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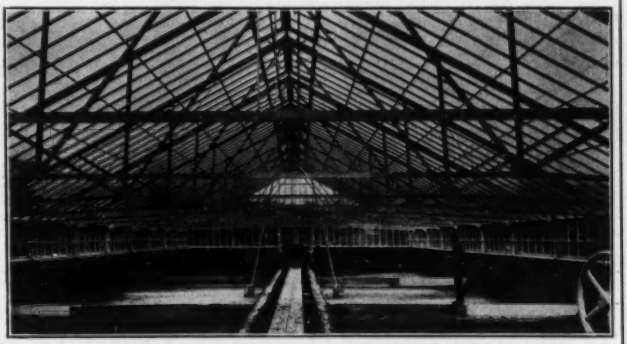

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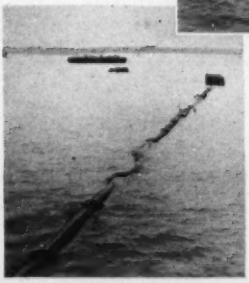

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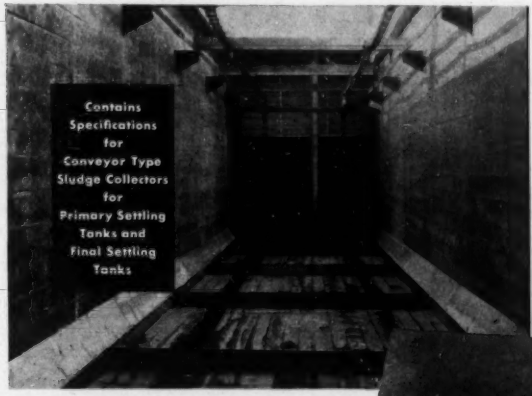

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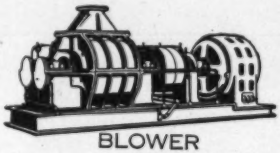

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Sewage Research

The Effects of Some Insecticides on the Sewage Sprinkling-Filter Fly, *Psychoda alternata**

WILLIAM W. FRYE WITH MAX LEVINE AND E. R. BECKER**

Introduction

The sewage-filter fly attracts attention because of the large numbers which breed in filter beds, and because of the annoyance to the people living near the filters. The adults are weak fliers, but the wind often carries them great distances from the filter beds. They are also very troublesome to filter operators and it is often difficult to work about the filters without a mask over the face.

During the summer of 1929 a request for a method of controlling these flies came from the Decker Packing Company of Mason City, Iowa. The company had just put into operation a new disposal plant with covered sprinkling filter beds. The flies became so abundant in the buildings housing this plant that it was almost impossible to go inside without a mask.

The first suggestion for the control of the flies was the reduction of the larvae by applying chemicals directly to the beds. This is a difficult procedure because of the danger of destroying the film and other organisms which are essential for the decomposition of the sewage constituents. The larvae live in this film, and the problem was to find some chemical which would be toxic to the larvae but which would not injure the film.

Habits and Life History.—Before investigating control methods, it was necessary to know something of the habits of the larvae and adults, and also to know the life history. Headlee (1919) states that the species in New Jersey winter as pupae and larvae in the filter beds. In Iowa the pupae are more abundant during the winter, with only an occasional larva. Warm weather, however, tends to increase the number of larvae. In the spring adult flies emerge and their numbers depend upon environmental conditions. Headlee also states that the abundance of flies is correlated with the thickness of the film covering the rocks.

The eggs are laid in masses on the stones and on the film covering the stones. These eggs are small, less than 0.5 mm. in length, ovoid in shape and of a pale white color.

* *Presented before the Fourth Annual Meeting of the Central States Sewage Works Association, Madison, Wis., May 22, 1931.*

** *From the Departments of Zoölogy and Bacteriology, Iowa State College, Ames, Iowa.*

The eggs hatch in from 24 to 48 hours. The time of hatching varies considerably with the temperature. After hatching, the larvae penetrate the film and adjust themselves so that the breathing tubes project through the film to the surface, while the body remains covered by the film. Here the larvae feed on the film and grow to maturity. The length of time in this larval stage is subject to extreme variation, but the average ranges from 9 to 15 days.

After the larva has reached maturity it transforms to the pupal stage. The pupa remains in the film with the breathing tubes projecting to the surface, but is not capable of moving about as actively as does the larva. The feeding also ends at pupation. The time necessary for development at this stage is also subject to considerable variation, but the average ranges from 24 to 48 hours during the warm summer months. When pupation is completed the fly emerges. The adult fly is not a strong flier and the movements from the filter are influenced by the wind. The flies usually rest on the upper surface of the stones, on the walls of the bed, and on the buildings near the beds. Considering the time necessary for development of the various stages, the life cycle would be completed in approximately two weeks during the summer months.

Control.—The habits of the adults are such as to make it very difficult under ordinary conditions to control these flies through the destruction of adult forms. A more suitable method might be to find some toxic substance that would destroy the larvae in the film. It would be necessary in this case to try to find some substance which would kill the larvae but which would not destroy the film.

Headlee (1918) tested a considerable number of chemicals, with a view to determining the minimum dosage for the larvae and the effects of these chemicals upon the life and activity of the film. In general, it was found that the minimum dosage which killed the larvae was also destructive to the film. The only possibility among the chemicals tested was hypochlorite of lime, this having been suggested by previous investigators. Hypochlorite of lime was applied through the dosing tank, the amounts varying from twelve to fifty pounds per acre. Actual counts made of the larvae showed that the kill was incomplete with the heaviest dosage, and the film was greatly injured. From these tests it seemed that chemical substances applied to the filter beds could not be used without destroying the film.

While conducting these tests with chemicals Headlee and Beckwith (1918) brought some stones into the laboratory and, desiring to keep them until the following day, covered them with tap water. When they examined the material the following day all the larvae were dead. This led to the idea that the fly larvae could be destroyed by drowning. By actual submergence of the entire filter beds it was found that in twenty-

four hours all the larvae and pupae were killed, with no apparent injury to the film.

Although the flooding method is reported to give 100% kill in twenty-four hours, it is not possible to flood many of the beds in small plants, because of their construction. This being the case in this particular locality, it was decided that a further study of chemical substances might prove fruitful.

The Effects of Some Insecticides on the Larvae and Film

Chlorination.—It is believed by some investigators that a heavy dosage of chlorine is effective in reducing the number of filter flies, by its

TABLE I

TOXIC EFFECT OF VARIOUS CONCENTRATIONS OF CHLORINE ON THE ORGANISMS IN SEWAGE FILTER FILMS

Concentration of Chlorine in Parts per Million	Time of Submergence			
	2 Hr.	8 Hr.	16 Hr.	20 Hr.
	Observations on Fly Larvae (Per Cent Killed)			
0	0	0	20	90
5	0	0	35	90
10	0	0	40	95
20	0	0	50	98
30	0	3	60	98
40	5	10	80	100
60	5	50	90	100
	Observations on Protozoa (Per Cent Killed)			
0	0	0	0	0
5	20	45	90	100
10	100	100	100	100
	Observations on Other Forms* (Per Cent Killed)			
0	0	0	0	0
5	0	0	5	10
10	0	4	20	25
20	0	6	28	30
30	0	10	35	40
40	10	15	38	60
60	25	75	90	98

* These include rotifers, nematodes, cyclops and the segmented worms.

effect on the larvae. After making a thorough survey of the literature it was found that no experimental attempts have been made to confirm this belief. Neither was there any reference made as to its effects on other animal forms which are normal inhabitants of the film. Chlorination does, however, cause sloughing, which would remove a large number of the larvae from the filter beds.

The amount of chlorine used in these tests was determined by the sodium thiosulphate-iodine method, using starch as an indicator.

Samples of the film were collected in ordinary wide-mouth quart fruit jars. Several small stones covered with the film were placed in these jars and brought to the laboratory. The stones were then covered with five hundred cc. of tap water containing the various amounts of chlorine. Samples were examined every hour to determine the per cent of kill for both the larvae and other invertebrates. The percentage killed is based on counts made on a total of one hundred organisms. A check with ordinary tap water was run along with the test materials.

TABLE II

TOXIC EFFECT OF VARIOUS CONCENTRATIONS OF NICOTINE SULPHATE ON THE ORGANISMS IN SEWAGE FILTER FILMS

Per Cent Nicotine Sulphate Solution	Time of Submergence			
	1 Hr.	2 Hr.	4 Hr.	8 Hr.
	Observations on Fly Larvae (Per Cent Killed)			
0	0	0	0	0
0.1	0	20	30	48
0.5	10	35	55	65
1.0	30	40	60	78
	Observations on Protozoa (Per Cent Killed)			
0	0	0	0	0
0.1	100	100	100	100
	Observations on Other Forms* (Per Cent Killed)			
0	0	0	0	0
0.1	5	16	18	20
0.5	25	25	40	50
1.0	45	50	75	93

* Rotifers, nematodes, cyclops and the segmented worms.

Table I shows the results obtained with various concentrations of chlorine. The results recorded in each of the tables included in the text are calculated from a series of ten observations.

The results of chlorination show that chlorine was more destructive to the other organisms in the film than to the *Psychoda* larvae. Relatively dilute solutions of chlorine killed the protozoa but had no marked effect on the higher invertebrates present. The fly larvae, nematodes and rotifers remained alive and active for several hours in solutions containing many times the amount of chlorine which was injurious to the protozoa in the film. This raises a serious question as to the feasibility of using chlorine for the control of the filter fly, but did give some interesting information as to the effects of chlorine on other animals found in the film.

Nicotine Sulphate.—The technique used with the nicotine sulphate solutions was the same as that described with chlorination tests. The

standard nicotine sulphate preparation (Black Leaf 40) was used as a base and dilutions were made from this standard (Table II).

Here again it was found that the use of nicotine sulphate would be inadvisable because of the destructive action on the organisms in the film, especially since the lower concentrations did not affect the larvae. With the highest concentrations of nicotine sulphate employed (1.0%) it was found that some of the larvae were still alive and active after being submerged for eight hours. Nicotine sulphate may also cause a sloughing

TABLE III

TOXIC EFFECT OF VARIOUS CONCENTRATIONS OF BORAX ON THE ORGANISMS IN SEWAGE FILTER FILMS

Per Cent Borax	Time of Submergence 1 Hr.	2 Hr.	4 Hr.	8 Hr.
	Observations on Fly Larvae (Per Cent Killed)			
0	0	0	0	0
0.1	0	0	5	12
0.2	0	15	20	48
0.5	10	25	75	83
0.8	25	35	78	90
1.0	50	75	95	97
	Observations on Protozoa (Per Cent Killed)			
0	0	0	0	0
0.1	10	30	60	70
0.2	30	65	95	100
0.5	100	100	100	100
	Observations on Other Forms* (Per Cent Killed)			
0	0	0	0	0
0.1	4	15	20	35
0.2	10	30	40	72
0.5	35	50	78	95
0.8	38	60	80	98
1.0	75	95	100	100

* Rotifers, nematodes, cyclops and the segmented worms.

which would tend to reduce the number of larvae, but the result is indirect and due to destruction of the film rather than the larvae.

Borax.—Results obtained with various concentrations of borax are shown in Table III. These results are, in general, the same as were obtained with chlorine and nicotine sulphate. It was noted, however, that borax is comparatively more toxic in low concentrations, but the minimum dosage is destructive to the film organisms. This information obtained in the laboratory again showed that it would be undesirable to use borax on the filter beds.

Other Insecticides.—Similar tests were conducted with carbon disulphide, pyrethrum, copper sulphate and various arsenates. It will

not be necessary to show in tabular form the results obtained with these chemicals. The results, as far as the insect larvae were concerned, were in general the same as with chlorine, nicotine and borax. All these substances when applied in amounts sufficient to kill the larvae were also destructive to the film. This destructive action on the film rendered the use of these insecticides on the filter beds undesirable.

Killing of the Adult Fly

After it was demonstrated that a suitable method of controlling the larvae without injury to other organisms was unlikely to be discovered, it was decided that we try to control the infestation of the filter beds by killing the adult flies. With the filter beds enclosed, spraying the walls and ceiling was considered as a possible method of reducing the number of adult flies.

Kerosene being very toxic to certain insects, and also quite cheap and easily obtainable, was considered first. Preliminary tests were conducted at the open filters located at Ames, Iowa. The results obtained by spraying the walls of the filter bed and the buildings about the plant indicated that kerosene might serve as a spray. By spreading papers along the walls and then applying a very fine spray, it was possible to collect a large number of the flies which had been covered with the kerosene. These flies were observed carefully and it was found that a large number recovered from the effects of the kerosene and became quite active after a few hours. In order to get a more toxic substance a small amount of pyrethrum flower was mixed with the kerosene and left standing for 12–24 hours. This kerosene-pyrethrum mixture was found to be much more toxic than the kerosene alone. Several preliminary tests were made to determine the amount of commercial pyrethrum flower necessary in kerosene to get an insecticide which would be reasonably efficient. It was found that $^1/_4$ to $^1/_2$ pound of pyrethrum flower mixed with one gallon of kerosene and left standing for 24 hours, with an occasional stirring, was from 95–100 per cent efficient.

After several preliminary tests with the kerosene-pyrethrum mixture at the Ames plant, it was used to spray the inside walls, roof and sides of the closed filter beds operated by the Decker Packing Company, located at Mason City, Iowa. The mixture was applied in a very fine mist by means of a power sprayer. Great care was taken to keep as much of the material as possible from getting on the surface of the filter beds.

Conclusions

1. At an enclosed sprinkling-filter plant handling packinghouse wastes and at a similar plant for creamery wastes, satisfactory results have been obtained by taking measures against the adult *psychoda* flies. Spraying

the walls and ceilings with a kerosene-pyrethrum mixture (1/4 to 1/2 pound pyrethrum flower per gallon of kerosene) was very effective in keeping the adult flies in check. The method might, of course, not be applicable to open filters.*

2. Chemicals used in an attempt to control the adult *psychoda* fly by destruction of the larvae in the filter films were not considered suitable. The chemicals used were: chlorine, nicotine sulphate (Black Leaf 40), carbon disulphide, pyrethrum, copper sulphate and several arsenate compounds.

* Some preliminary observation on the Ames, Iowa, open filter indicates that considerable relief may be obtained.

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After-Effect of Ferric Chloride on Sludge Digestion*

BY WILLEM RUDOLFS** AND LLOYD R. SETTER***

Results of studies of the effect of iron on the decomposition of sewage solids, published by one of us,[10] showed that gas production from sewage sludge was not affected by the addition of small quantities of ferric chloride to the sewage, but that it was progressively retarded by addition of quantities ranging from 5 to 20 p. p. m. Ultimately more gas was produced per gram of volatile matter when these amounts of ferric chloride were added. The question arose as to what would happen if ferric chloride were added continuously as a coagulant, so that the ripe sludge would possibly contain considerable quantities of iron compounds. Would this retardation become more and more pronounced, or would the sludge eventually contain specific types of flora and fauna which might prefer relatively large quantities of iron?

In view of the favorable results obtained at plants where moderate quantities of iron waste are received, and in connection with some experiments conducted with fresh solids and ripe sludge from the Trenton, N. J., plant, where the sewage contains pickling liquors, it was thought of general interest to devote further study to this problem. The results obtained are not conclusive, since our attempts to duplicate actual plant conditions in determining the effect of ferric chloride on digestion, after it has been used as a coagulant, were possibly not correct nor wholly successful. The experimental conditions imposed were rather more severe than would be obtained in practice. However, the results showing certain tendencies were thought of sufficient interest to warrant publication at this time.

Methods and Procedure

Fresh solids, collected in pails hung in the sedimentation tanks at the Plainfield disposal plant, were treated with ferric chloride solutions. The treatment was based upon an addition of 40 p. p. m. $FeCl_3$, which field studies had shown to produce very good flocculation. Four liters of fresh solids containing about 95 per cent moisture were placed in a carboy and diluted with 15 liters of tap water. To this was added 53.2 grams of $FeCl_3$ in the form of a commercial acidic 49% $FeCl_3$ solution. The mixture was thoroughly shaken and allowed to stand until the settleable solids had collected in the bottom of the carboy. For the purpose of washing out the acid of the $FeCl_3$ solution, the supernatant liquid, amounting to approximately 9 liters, was siphoned off and replaced with water. After again

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thoroughly mixing the contents of the carboy, the solids were allowed to settle and the supernatant liquid was again replaced by water. After a third washing the solids were allowed to settle for 18 hours, so that, following the final decantation, a volume of slightly greater than four liters was obtained. It is apparent that this treatment does not duplicate actual plant conditions because in the initial treatment the $FeCl_3$ concentration was much greater, namely, about 2500 p. p. m. on the basis of the diluted sludge volume, or about 1000 p. p. m. on the basis of the total volume of wash water, and also on account of the washing procedure. Nevertheless, the chemical treatment was rather severe in comparison with actual operation and the results obtained should therefore be more pronounced or show in a shorter time what ultimately would happen. It is of interest to note that this excessive $FeCl_3$ treatment resulted in a very porous sludge which resembled activated sludge in color and appearance, and looked very similar to the floc present in settling tanks at plants where quantities of iron are received.

TABLE I

ANALYSES OF FRESH SOLIDS AND RIPE SLUDGE

Material	Solids, Per Cent	Ash, Per Cent	pH
$FeCl_3$ treated fresh solids	4.66	22.1	4.8
Untreated fresh solids	6.25	22.9	5.0
$FeCl_3$ treated ripe sludge	7.68	54.0	7.2
Untreated ripe sludge	7.37	51.0	7.4

For comparison and control material, untreated fresh solids were washed similarly, but only twice instead of three times, since turbidity determinations on the supernatant liquids showed that more colloidal, pseudo-colloidal or finely divided materials were present in the supernatant liquid of the untreated fresh solids than in the liquid decanted from the coagulated solids.

Two different ripe sludges were used for seeding purposes. One was sludge obtained from Plainfield and originally divided for use in experiments on the effect of iron on digestion. A mixture of fresh solids and ripe sludges had been treated for 75 days and stored in the laboratory. This mixture had reached its peak of gasification on the 68th day and after 75 days had produced 605 cc. gas per gram of volatile matter added. At that time it still produced small quantities of gas, but after storage for an additional six weeks it could be assumed to be well digested. The other ripe sludge was the unused portion of the Plainfield sludge.

Analyses of the treated and untreated fresh solids and ripe sludge used for the first series of experiments are give in Table I.

The following mixtures were made on a 2 to 1 ratio of volatile matter of fresh solids and ripe sludge. They were incubated at 80° F., gas was col-

TABLE II

SOLIDS, ASH AND pH VALUES OF VARIOUS MIXTURES OF FRESH SOLIDS AND RIPE SLUDGE, INCLUDING THOSE TREATED WITH FERRIC CHLORIDE

Mixtures	A			B			C			D		
	Treated F. S. + Untreated R. S.			Untreated F. S. + Untreated R. S.			Treated F. S. + Treated R. S.			Untreated F. S. + Treated R. S.		
Days Digestion	Solids, Per Cent	Ash, Per Cent	pH	Solids Per Cent	Ash, Per Cent	pH	Solids, Per Cent	Ash, Per Cent	pH	Solids, Per Cent	Ash, Per Cent	pH
0	5.56	35.1	6.9	6.74	35.7	6.8	5.75	35.9	6.6	6.98	37.4	6.5
13	5.10	41.8	7.4	5.80	40.1	7.6	5.30	40.4	6.0	6.00	40.0	6.8
25	4.32	44.8	7.2	5.18	44.7	7.6	5.01	39.4	6.4	6.00	40.1	6.4
35	4.10	46.3	7.5	5.00	46.0	7.5	4.90	39.2	6.8	5.74	40.3	7.4
55	4.01	47.0	7.8	4.83	48.2	7.7	4.84	41.3	7.2	5.70	43.0	7.7

F. S. = Fresh solids.
R. S. = Ripe sludge.

lected daily and analyses of solids and ash were made weekly on separately incubated portions of the mixtures:

A. $FeCl_3$ treated fresh solids and untreated ripe sludge.

B. Untreated fresh solids and untreated ripe sludge.

C. $FeCl_3$ treated fresh solids and $FeCl_3$ treated ripe sludge.

D. Untreated fresh solids and $FeCl_3$ treated ripe sludge.

Results

The condensed results of solids, ash and pH determinations, made at intervals, are given in Table II. It appears from the percentage of ash that the untreated mixture had progressed most and the completely treated mixture least. The pH values indicate that the latter produced considerable acidic products which accumulated and were only slowly destroyed. No such accumulations of acidic products were found in the untreated mixtures.

The cumulative gas production from the different mixtures is graphically shown in Figure 1. The untreated mixture produced the greatest quantity of gas per gram of volatile matter added, followed by the mixture in which the fresh solids only were treated. It is of considerable interest to note that gas production from the mixture with $FeCl_3$ treated ripe sludge produced but little more gas than the mixture in which both the fresh solids and ripe sludge were treated. It would seem, therefore, that the treated ripe sludge was the most important factor in the retardation of gas production. Although gas production was greatly retarded by the ripe sludge which had previously received $FeCl_3$, it cannot be said that gasification was completely inhibited. The time re-

quired was far greater than for the ripe-sludge mixture which had not previously received $FeCl_3$. The treatment of fresh solids resulted in the production of an intermediate quantity of gas, but additional time was not required. As a matter of fact, digestion of this mixture seemed to be completed sooner than usual. This is perhaps better illustrated in Figure 2, where the daily gas production is shown of the control mixture and the mixture in which only the fresh solids had been treated with $FeCl_3$.

The percentage reductions of volatile matter in the different mixtures, after a certain number of days, are given in Table III. Although during the first 13 days the digestion activities were progressively affected

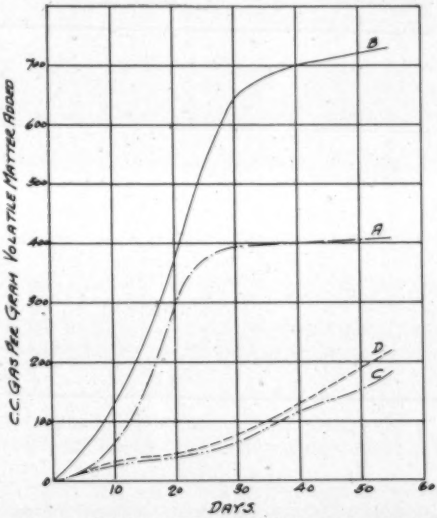

FIG. 1.—Cumulative Gas Production from Different Mixtures. A = Treated Fresh Solids and Untreated Ripe Sludge; B = Untreated Fresh Solids and Untreated Ripe Sludge; C = Treated Fresh Solids and Treated Ripe Sludge; D = Untreated Fresh Solids and Treated Ripe Sludge.

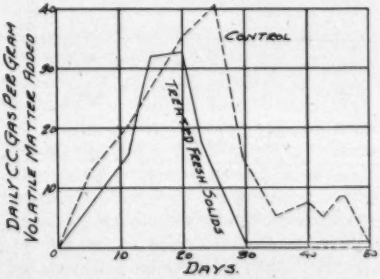

FIG. 2.—Daily Gas Production.

adversely by treatment with $FeCl_3$ of the fresh solids alone, ripe sludge alone and both fresh solids and ripe sludge, considerable reduction in volatile matter took place even with the most complete treatment. The treated mixtures (C and D) produced, however, little gas, so that the change in volatile matter must have been mainly in the nature of lique-

faction. After the initial liquefaction of the mixtures in which ripe sludge and fresh solids and ripe sludge alone were treated, the processes progressed very slowly.

TABLE III

VOLATILE MATTER, PER CENT REDUCTION

Days	A*	B*	C*	D*
13	17.8	20.2	14.2	15.2
25	34.0	34.2	16.4	17.5
35	39.0	38.0	19.0	21.3
55	41.2	42.5	22.8	23.0

* See Table II.

Discussion

For a comparison of the behavior of the mixtures, the calculated total gas production per gram of volatile matter added, and the gas produced per gram of volatile matter destroyed after certain periods of incubation, are given in Table IV. The differences are striking. After 55 days the treated fresh solids produced 56% as much gas as the control mixture, while the mixture with the treated ripe sludge produced 30% as much gas, and the mixture in which both ripe sludge and fresh solids were treated only 25% of the gas, per gram of volatile matter added. Gas production per gram of volatile matter destroyed was only half as much from the treated mixtures as from the control. Since volatile matter reduction was but slightly less during the first two weeks in the treated mixtures than in the control, it would seem that liquefaction was not greatly hampered by the added chemical.

TABLE IV

GAS PRODUCTION PER GRAM OF VOLATILE MATTER ADDED AND DESTROYED

	A*		B*		C*		D*	
Days	Added, Cc.	Destroyed, Cc.	Added, Cc.	Destroyed, Cc.	Added, Cc.	Destroyed, Cc.	Added, Cc.	Destroyed, Cc.
13	99	557	173	856	30.5	215	39.7	228
25	373	1100	529	1545	48.0	292	50.7	290
35	396	1003	681	1980	91.8	483	102	478
55	408	990	730	1730	185	810	218	925

* See Tables II and III.

These results are similar to those obtained with the addition of other chemicals and carbonaceous compounds. Results of previous research show that if certain quantities of H_2SO_4, HCl, acetic or butyric acids, milk waste, certain fats and other acid-producing compounds are added, liquefaction is not impaired and in some instances is actually greatly stimulated, whereas gasification may be completely stopped. This liquefaction does not necessarily mean the production of stable end products, but in many instances the production of volatile compounds, which upon drying

are lost into the air. Ordinarily, during the disintegration and decomposition of solid organic matter, liquefied compounds are produced which in turn are gasified.

When certain chemicals or compounds are added they may affect the flora and fauna in three ways:

1. Certain groups of organisms may be stimulated greatly and others repressed, or
2. The degradation of the organic matter may proceed along different lines, producing different end products, or
3. Intermediate decomposition products may react with the chemical and be "locked up" (in some cases at least temporarily) until a new flora has been developed.

When liquefaction is predominant, either the liquefying organisms are stimulated and cause accumulation of the materials, usually in the form of organic acids which are later attacked by the gasifying organisms, or the gasifiers are affected to such an extent that their activities are retarded, and they cannot catch up with the work of the liquefying organisms until conditions are changed. This occurs when unseeded fresh solids are incubated, containing large numbers of acid-producing organisms and few gasifiers. The acid-formers change the reaction of the medium to such an extent that the environment for the gasifiers becomes unfavorable, and gasification is greatly retarded. But when the medium is made more favorable by the addition of an alkali the gasifiers are stimulated and digestion proceeds in the "normal" way. This same process may take place when large quantities of acid-producing organic compounds are present, which upon decomposition change the reaction of the medium.

The addition of certain inorganic chemicals may cause decomposition to proceed differently. The quantities and types of intermediate degradation products are altered, without the production of large amounts of organic acids. The flora may be affected by selective killing or selective stimulation.

Reaction of certain chemicals with intermediate and end products are known, for instance, the reaction of iron with certain protein compounds, amino acids and hydrogen sulphide. The resulting compounds may remain for some time until a flora has been developed which can attack them, or such compounds may remain unattacked for such a long time that, from a practical sewage-treatment standpoint, they might be considered as permanent.

Some preliminary experiments were conducted with the sludges obtained from the above experiments. Additional results were obtained from digestion experiments with fresh solids and ripe sludge procured from the Trenton, N. J., sewage disposal plant, which receives, among other wastes,[8] comparatively large quantities of iron compounds.

The sludges obtained from the mixtures treated with $FeCl_3$, as reported in the previous experiment, were used for further experimentation to determine, if possible, the after-effects of the treatments. Analyses of the ripe sludge used and fresh solids added were as follows:

Second Generation Ripe Sludge	Solids, Per Cent	Ash, Per Cent
A-1	3.77	48.8
B-1	3.89	48.4
C-1	4.27	42.5
D-1	5.58	43.2
Fresh solids	5.57	20.9

Results obtained after 10 days' incubation are of particular interest. Total gas production per gram of volatile matter added was as follows:

A-1	149 cc.
B-1	244 cc.
C-1	335 cc.
D-1	525 cc.

The cumulative gas productions from the different materials during this period are shown in Figure 3. Gas production from the mixtures which were seeded with ripe sludge that had previously been treated with $FeCl_3$, and also had been used for seeding (mixtures C and D, former experiment, and C-1 and D-1, present experiment) was rapid and copious. The mixture A-1 produced the least gas, similar to the mixture which in the previous experiment had treated only ripe sludge (D). Mixture A-1 was therefore again a check on the retarding effect noticed in the former experiment when untreated fresh solids were added to treated ripe sludge. The results of the second series of experiments together with the knowledge of other experiments might indicate that:

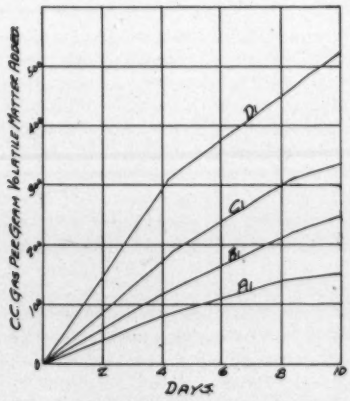

FIG. 3.—Cumulative Gas Production from Second "Generation" Sludge.

1. The retardation of the rate of digestion is due to the effect of $FeCl_3$ on the flora.
2. Certain volatile substances are temporarily "fixed" or "locked up."

3. When a new flora is developed, which is stimulated by iron, the "locked-up" volatile substances are gasified.

A search of the literature brought to light some supporting evidence for this reasoning. It is well known that certain iron compounds, especially $FeCl_3$ through its coagulative power and precipitate-forming properties, function as an aid in purification of sewage. These coagulated substances are readily attacked, when the quantity of precipitant is small and the flora is not appreciably affected, and may even stimulate somewhat the digestion activities (Rudolfs and associates,[8] Setter[10]). Several papers dealing with the effect of iron on micro-organisms on their media have appeared. Baudisch and Welo[1] have prepared an active iron compound by heating equal amounts of Fe_3O_4 and Fe_2O_3 to 300° C. They have called this compound "active iron oxide." In testing Fe_3O_4, active iron oxide and Fe_2O_3 these investigators found that the former two oxides when added to broth cultures will maintain the virulence of *Bacterium lepisetium* while iron-free medium will not. Further these two oxides give a positive benzidine–hydrogen peroxide blood test and function similar to blood.

J. P. Scott[9] found that the addition of 0.2% ferric sulphate to culture media stimulated *Cl. chauvoei* to such an extent that avirulent strains regained their virulence. The same concentration of $FeCl_3$ produced one-half as much virulence as $Fe_2(SO_4)_3$ whereas $FeSO_4$ had no effect. The investigator also found that iron salts stimulated specific carbohydrate fermentation, especially if the amount of peptone was increased. In this case the ferrous salts had the greater influence.

Harpuder showed that $FeSO_4$ in concentrations of 10^{-3} mol inhibits the fermentation of yeast, whereas in a concentration of 10^{-5} mol fermentation is increased, and at a concentration of 10^{-6} mol there is no effect.

In 1928 the same author[4] found that ferrous ions had a definite effect on enzymes. The activity of salivary diastase and pepsin are inhibited by ferrous ions of concentration 10^{-3} mol and stimulated by concentrations near 0.5×10^{-7} mol. Trypsin showed only a slight inhibition at the higher iron concentration.

Tammann and Rienäcker[11] in their study of the poisonous action of some metals and metallic alloys on bacteria reached the conclusion that iron was only slightly toxic to the growth of *B. coli communis, B. brassicae, Sarcina agilia, B. gassypii and Penicillium glaucum* on agar-agar nutrient media at 35° C. The toxicity was explained by the formation of a complex organic compound.

Hotchkiss[5] studied the toxic effect of a large number of cations on *Bacterium coli*. Each cation was added as the chloride to a 1% peptone media. Growth of the organisms after a three-day digestion period was indicated by turbidity tests. The toxicity of the cations was divided into two groups, one in which no growth occurred in concentrations of 2 to 0.05

molar and a second group where 0.01 to 0.0001 molar concentration was sufficient to prevent growth.

Of particular importance in this respect is the toxicity of iron chlorides. Hotchkiss found that the hydrolysis of ferric chloride was such that even in concentrations of 0.00001 mol the reaction was materially changed. Further the iron chlorides, especially $FeCl_3$, caused a precipitation of some of the peptone, which did not occur when HCl was added to bring the pH down to that of the $FeCl_3$-peptone solution.

$FeCl_3$ was found to be only slightly toxic in concentrations as low as 0.00005 molar, *i. e.*, the bacterial count at this concentration was 550 million against 700 million in the control. At 0.001 molar concentrations both $FeCl_3$ and $FeCl_2$ were toxic and no growth occurred.

There appeared to be no marked difference in the toxicity of the ferrous and ferric chlorides. Similar results were obtained by Eisenberg[3] but Matthews[4] found $FeCl_2$ to be much more toxic than $FeCl_3$. At no time was iron found to be stimulating.

Resnikoff[7] investigated the action of chlorides of Pb, Hg, Cu, Fe and Al on the protoplasm of *amoeba proteus*. With the exception of $HgCl_2$, $FeCl_3$ was the most toxic and $FeCl_2$ the least toxic on the membrane of the cell after one-day immersions. After five days of immersion, $FeCl_3$ was nearly as non-toxic as $FeCl_2$.

Creighton[2] investigated the behavior of iron salts in the presence of proteins and other organic substances. The ferric-iron combined with the protein and was held by primary and secondary valence bonds. The presence of the protein prevented the ordinary reactions of iron salts from occurring. Thus, $FeCl_3$ in the presence of protein could not be precipitated by the addition of NH_4OH or NaOH. Further, the addition of Prussian blue to albumin or gelatine resulted in a rapid fading of the blue color. Creighton also found that sucrose, glycerol and tartaric acid do not appear to form chemical adsorption compounds with either ferrous or ferric salts.

Retardation as well as stimulation may result from addition of iron salts, but not much is known of the possibility of specific types of flora and fauna which prefer relatively large quantities of iron. In view of the fact that digestion tanks receiving quantities of iron waste produce a ripe sludge, which is satisfactory for seeding fresh solids of the same plant or even fresh solids of a different plant, which hastens digestion, which produces the same quantity of gas per gram of volatile matter destroyed as other ripe sludge, but less total gas, together with the indications of the above experiments, it would seem logical to conclude that certain volatile substances are fixed by $FeCl_3$ treatment, and when the proper flora is developed these "fixed" volatile substances might again be broken down. The development of a specific flora would not necessarily mean that these "fixed" volatile substances are *per se* further decomposed. Environmental factors such as

time, temperature and reaction may play an important rôle, with the result that the partially "fixed" fresh solids introduced are decomposed only far enough to produce a stable sludge, without a breaking down of the "fixed" material itself. The more information we obtain on digestion, the clearer it becomes that the flora can be changed to meet changed conditions or a flora can be developed with continuous experimentation which behaves markedly different from the original one. This is particularly true when chemicals or large quantities of specific organic compounds are added, or when temperature changes are made. Further results along these lines will be published later.

Summary

Different mixtures of fresh solids and ripe sludge were made, in which either the fresh solids, ripe sludge, or both, were treated with $FeCl_3$. Gasification was markedly retarded when treated ripe sludge, or treated fresh solids plus treated ripe sludge were used. Treated fresh solids alone hastened the rate of digestion but produced less gas. During the first part of the experiment liquefaction was not hampered.

The ripe sludges produced from the different mixtures were again used for seed material to determine the after-effects of the treatment. Preliminary results showed a marked increase in gas production from the mixtures containing ripe sludge previously treated with ferric chloride. It is contended that under certain conditions certain groups of organisms may be stimulated and others repressed; that the degradation of organic matter may proceed along different lines; and that intermediate decomposition products may react with the chemical added and "locked-up." This locked-up material may be broken down when a new flora has developed. A new flora can be built up, or changes in equilibrium made, to meet changed conditions. The building up of a new flora can be accomplished by different environmental factors.

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The Biology of Activated Sludge—An Historical Review*

BY A. M. BUSWELL**

It is well known that there are two groups of reactions which take place during the removal of colloids from sewage: (*a*) bio-precipitation and (*b*) oxidation or nitrification, as the latter is usually called. Bio-precipitation is accomplished by larger organisms, the chlamydobacteriaceae or "giant bacteria," the fungi (especially molds), the larger protozoa and certain higher animals. These organisms are found to compose the bulk of the growth in the floc. A certain amount of oxidation is accomplished incidentally by these organisms since they give off carbon dioxide. They also break down nitrogenous organic matter with the formation of ammonia in some cases, and to that extent aid the second or nitrification process.

J. W. H. Johnson[1] appears to have been the first to report on the microscopic growth of activated sludge. His findings in brief are as follows:

"Microscopically, the bulk of the mud (sludge) shows nothing very characteristic, but the repeated presence of *Opercularia* suggests an association which I have noticed in rapidly flowing water where *Zoögloea ramigera* was the dominant organism, and from experiments now in operation it seems possible that zoögloea, assisted by other minute organisms chiefly of *animal origin*, may be responsible for the rapid purification thus effected. That such minute animal life, *i. e.*, protozoa, rapidly destroy nitrogenous substances is proved by the increased amount of nitrogen and its derivatives observed when soil is partially sterilized, and the protozoa are thus destroyed.

"Whatever may be the *modus operandi of* this purification, the process has been developed along lines of natural biological evolution; each improvement in the method of aeration has produced a corresponding increase in the number and the variety of organisms which were capable of participating in the oxidation of the polluting organic matter, and has thus given an increased efficiency."

Some of the earlier writers make especial mention of nitrifying bacteria. Bartow and Smith[2] noticed large numbers of worms (*Aeolosoma Hemprichii*) as well as vorticella and rotifera at times in the sludge. Purdy[3] counted the various protozoa in strawboard waste, activated in a 3-inch glass tube and fed by the fill-and-draw method. He followed the usual Sedgwick-Rafter method for enumerating the microscopic organisms, reporting the zoögloea flocs in standard units of 0.0004 sq. mm. He used a 500-cc. aerating vessel operated with an unmeasured excess of air on the fill-and-draw system with

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24-hour aeration periods. This system served admirably the purposes of the particular investigation, which showed the presence of relatively large numbers of protozoa, especially of peritrichs. Some work of the present author on a similar scale and with excess of air and 24-hour fillings gave similar results. They do not seem to correspond to results obtained when smaller amounts of air are used, nor with the results on larger experimental units.

Richards and Sawyer[4] in 1922 presented data including chemical analyses, bacteria counts and microscopic determinations of the number of protozoa. A relation was established between the numbers of protozoa and bacteria. The high nitrogen in the activated sludge was attributed to synthetic living protein of the bodies of bacteria and protozoa. Under certain conditions of aeration free ammonia and nitrates were synthesized into proteins, as contrasted with the formation of free ammonia and nitrates which is ordinarily observed in the activated-sludge process.

Buswell and Long[5] have studied the organisms of activated sludge from both the qualitative and quantitative standpoint. Their report follows:

> The analytical data herewith reported refer to samples taken from the aeration chambers of a two-tank activated sludge unit fully described elsewhere.[6]
>
> Microscopic observations made during the winter of 1920–21 indicated a relation between the amount of air used, the strength of the sewage, the settling rate of the sludge and the types of organisms composing the sludge. When in the spring, after a shutdown for repairs, the plant was started up without any activated sludge as a "starter," daily microscopic observations were made to follow the changes in microbial life as the sludge built up. The daily records are given in the original article. In general it is to be noted that the holotrichs were the first to appear in noticeable numbers but that they gave way in time to other forms. The peritrichs (*Carchesium* and *Vorticella*) appeared only after several days of aeration. The matured sludge seemed to be composed largely of zoögloeal masses with frequent colonies of peritrichs and occasional hypotrichs (generally *Euplotes*).
>
> In the study of the microbiology of activated sludge in its development from raw sewage there seems to be a definite succession or addition of forms as the sludge develops. Beginning with the characteristic microörganisms of raw sewage as it is taken into the aeration chamber, there is a predominance of the minute flagellates and ciliates, with occasional peritrichs and holotrichs. In a few days the minute forms diminish in number until they become a negligible quantity, while peritrichs, holotrichs and heterotrichs increase in number, the peritrichs predominating throughout. As the minute forms become insignificant the gelatinous masses of the chlamydobacteriaceae and nematodes appear to be followed in a few days by the sudden appearance of peritrichs. This point then brings us to the character-

istic fauna and flora of the matured activated sludge, under the particular conditions of operation employed. Observations on the occurrence of the various groups of organisms have been summarized as follows:

Fauna of the Sludge

Ciliates and flagellates constituted practically the entire animal life during the first week of accumulation of sludge, afterward decreasing to negligible numbers. Peritrichs became the predominating organisms after the first week, reaching a count of 14,000 per cubic centimeter in 11 days. *Vorticella* was most common. Occasional colonies of *Carchesium* were found. Colonies and individuals were invariably attached to the amorphous particles of the sludge.

Hypotrichs of the *Euplotes* type reached a maximum count of 4500 per cubic centimeter, but usually were found in lesser numbers. Holotrichs and heterotrichs varied widely, and were frequently completely absent.

Rotifers were practically absent at all times. In small-scale experiments using large amounts of air, rotifers became more abundant.

Nematodes reached a maximum count of 3300 per cubic centimeter and thereafter gradually decreased.

Zoögloeal Masses

Having briefly reviewed the fauna of the sludge, we should turn our attention to the sludge proper. Two days after start of operation with raw sewage, units of zoögloeal mass numbered 115,000 per cc.; after 10 days, 1,089,500; after 15 days, 2,062,500. The count continued ranging between one and two million units throughout the period, a count typical of a matured sludge maintained at the given dilution.

The animal inclusions of the sludge made up a very small part of the entire mass. The base of the sludge was composed of zoögloeal masses intermixed largely with filamentous bacteria and occasional Zoögloea *ramigera*.

The filamentous forms overwhelmingly predominated the sludge. The literature on filamentous forms is scattered and rather uncertain taxonomically. *Crenothrix polyspora*, *Sphaerotilus dichotomus* and *Zoögloea ramigera* were present in large numbers.

Bacterial Surface

Hering[7] long ago pointed out the importance of bacterial surface in sewage purification, though few definite data have been developed since his paper on the subject. We may obtain a notion of the order of magnitude, at least, of the sludge surface in the activated-sludge process. Take a case where two million standard units of zoögloeal masses were found per cubic centimeter in the aeration tank. Each floc must have a lower surface equal

at least to the upper surface, so that, leaving out the side surfaces, we would have four million standard units of 0.0004 sq. mm. each or 16 sq. cm. of surface per cubic centimeter of volume. This computation does not include the surface of the protozoa or the free-swimming bacteria. If increased by fifty or one hundred per cent it would probably approach more closely the correct value. This would mean a surface of approximately 500 sq. ft. of sludge surface in 1 cu. ft. of the aeration chamber.

Definition of Activated-Sludge Flocs

Activated-sludge flocs are composed of a *synthetic* gelatinous matrix similar to that of *Nostoc*, or *Merismopedia*, in which filamentous and unicellular bacteria are embedded and on which various protozoa and some metazoa crawl and feed. The purification is accomplished by ingestion and assimilation by organisms of the organic matter in the sewage and its re-synthesis into the living material of the flocs. This process changes organic matter from colloidal and dissolved states of dispersion to a state in which it will settle out.

Bio-Precipitation

To demonstrate further the occurrence of bio-precipitation, Shive with Buswell[8] cultivated *B. subtilus* in pure culture in large flasks of peptone broth, maintaining a vigorous agitation throughout the incubation. At the end of the incubation the growth of subtilis was allowed to settle and the supernatant liquor analyzed.

Microscopic examinations and pH determinations were made on liquor from the three series of cultures (24, 48 and 72 hr.). The results of this work are shown in Table I along with the percentage of total nitrogen precipitated. The various concentrations of broth that were used are expressed in terms of their total nitrogen content. It is seen from the table that the maximum precipitation of nitrogen in each case took place during the first 48 hours of aeration. After 48 hours spore formation set in or the cells began to break up, with the result that part of the nitrogen of the cells went back into solution and part remained suspended in the form of bacterial cells in the supernatant liquor and would not settle out.

Observations of spore formation, indicated in the table, furnish evidence for the support of the theory that spore formation is due to lack of food rather than the accumulation of products of metabolism. During the first 24 hours of aeration no spores were formed in any of the concentrations of broth used. At the end of 48 hours spore formation had progressed rapidly in the lower concentrations but no spores were present in the concentration having a nitrogen content over 500 milligrams per liter. At the end of 72 hours all of the concentrations showed that nearly all of the vegetative cells had changed over to spores, with the exception of the culture in full-strength

broth, which had not yet shown evidence of spore formation although the chains were rapidly breaking up. Spore formation did not occur in the latter culture until the fourth day of aeration.

TABLE I

BIO-PRECIPITATION BY *B. Subtilis*

Total Nitrogen, Mg. per Liter	pH	Spores	Per Cent of Total Nitrogen Precipitated
	24 Hours		
61.37	7.4	−	1.5
142.80	7.4	−	6.4
589.71	7.8	−	4.7
1223.77	8.4	−	6.2
	48 Hours		
59.25	8.2	++	7.7
119.77	8.4	++	8.4
578.75	8.2	−	17.1
1223.75	8.6	−	12.9
	72 Hours		
65.46		+++	0.0
118.90		+++	1.8
494.32		+++	8.6
1196.52		−*	7.7

* Spores did not form until the 4th day of aeration.

Key: − No spores. + Few spores. ++ Many spores. +++ Nearly all spores.

In these experiments the "bulking" of activated sludge frequently observed by plant operators[9] has been duplicated under completely controlled conditions. In this case the phenomenon was clearly due to the age of the culture. Whether the same cause is effective with the mixed growths found in practice remains to be demonstrated.

Further Biological Studies

The next study of the microbiology of activated sludge we find is by Kolkwitz.[10] He studied the activated sludge at the Ruhrverband plant in Essen-Rellinghausen and reported a list of bacteria and protozoa similar to the one reported by Buswell and Long.[11] In overloaded or overripe sludge, Kolkwitz noted a retrogression of hypotrichs and peritrichs.

The general realization that microörganisms are of fundamental importance in the activated-sludge process is evidenced by the persistence with which that field has been studied during the last few years.

Agersborg and Hatfield,[12] in a rather extensive study, found that:

"1. The sludge in the pre-aeration system consists almost entirely of Zoögloea and *Sphaerotilus*.

"2. Increased aeration favors the succession of small flagellates, hypotrichous and then peritrichous ciliates.

"3. This sludge, although relatively free from protozoa and classified as a poor activated sludge, causes a reduction of about 30 per cent of the total B. O. D. in the crude sewage.

"4. The presence of about 8 p. p. m. of dextrose in the sewage probably encourages the abundant growth of *Sphaerotilus* in the aeration tanks and may also count for its presence in Imhoff tanks."

Morgan and Beck[13] and Ruchhoft and Watkins[14] used the microscopic method of attack in studying a condition of "bulking" and came to the conclusion that the difficulty was due to a growth of *Sphaerotilus* stimulated by carbohydrates.

A very carefully controlled study of the relative importance of bacteria and protozoa was reported by Ardern.[15] The following description of his experimental method is worth consideration:

"For the experiment, two glass vessels (capacity, 2–3 liters), fitted with diffusers and adapted for the treatment of sewage by the activated-sludge process on the "fill-and-draw" principle, were taken. To one vessel (A) was added a nitrifying sludge which had been previously built up with care, and contained relatively few protozoa. To the second vessel (B) was added an equal volume of the same sludge and 600–700 large-sized clusters of *Carchesium* freshly isolated from activated sludge. Both sludges were then treated with successive volumes of sewage over several weeks—allowing a volume of 700 cc.'s of liquor (sludge and effluent) to remain after each decantation and adding 1600 cc.'s of sewage at each filling."

Ardern's conclusions, which differ from the views of Cramer,[16] are as follows:

"1. That the different species of protozoa found in activated sludge are indicative of the condition of the sludge.

"2. That in the treatment of sewage by the activated-sludge process, under suitable aeration conditions, protozoa have no adverse influence on the settling properties of the sludge.

"3. That, from the standpoint of sewage treatment in general, protozoa play no important part in the process of purification by activated sludge, although it is possible they facilitate the production of a more highly clarified effluent. This table appears to support the observation of Haigh Johnson* that paramoecia accompanied effluents of unusual purity and the suggestion that protozoa help in the removal of fine particles of suspended matter and the surplus bacteria, but this investigation has not included any experiments designed to demonstrate such a relationship between protozoal and bacterial content of the final effluent."

Taylor[17] has recently made a biological survey of the activated-sludge

Proc. Managers of Sewage Treatment Works Assoc., **54**, 1922.

process, and observed the presence of the usual animal and bacterial forms. It is interesting to note that this author presents experimental proof that zoögloeal bacteria are important purifying agents.

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Partial and Complete Sterilization of Activated Sludge and the Effect on Purification*

BY H. HEUKELEKIAN**

Considerable discussion has been published recently concerning the relative rôle of bacteria and protozoa in the purification of sewage by the activated-sludge process. Years ago studies were made by Buswell and Long,[2] Arder and Lockett,[1] Richards and Sawyer[5] and others dealing with this subject. Cramer[4] has attributed to protozoa a very important rôle in the clarification of sewage. Butterfield and Purdy[3] state that protozoa assist in purification by keeping down the numbers of bacteria. Others claim that the presence of protozoa is of symptomatic value in that the preponderance of certain types such as *vorticella, carchesium and opercularia* indicates a well-aerated sludge, while the preponderance of small flagellates indicates a poorly aerated sludge.

The diversity of opinion is not strange when one considers the difficulty of the problem itself. It is difficult to eliminate the protozoa without partially affecting bacterial life and vice versa.

Wagner[6] added potassium cyanide (1:10,000) and quinine hydrochloride (1:2500) to sewage and aerated continuously for from 19 to 26 days, with daily additions of fresh sewage. He determined the turbidity, methylene blue reduction and oxygen consumed and tested qualitatively for ammonia, nitrites and nitrates. He also determined total bacteria, *B. coli* and protozoa. The addition of potassium cyanide and quinine hydrochloride inactivated and reduced the numbers of protozoa for a week, after which time their numbers increased. The addition of these substances stimulated the growth of bacteria initially, but when the protozoa began to increase the numbers of bacteria were reduced to their original level. The turbidity and putrescibility and oxygen consumption of the sewage were increased. This impairment of purification lasted until the protozoa began to increase. The addition of sodium hypochlorite to that point of residual chlorine with starch-iodide inhibited the growth of not only the protozoa but also the bacteria. But soon afterward the bacterial numbers increased, while the protozoa increased very slowly. The effect on purification did not correspond with the fall and rise of bacterial population, but with the fluctuation in numbers of protozoa.

Wagner concluded from these results that protozoa play a very important rôle in the purification of sewage. Bacteria free the flocs from adsorbed material and maintain the adsorbing power of the flocs. Large numbers of bacteria do not necessarily mean better purification, but, on the contrary,

* *Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Sewage Research.*

** *Associate, Dept. Sewage Research.*

a limited number of bacteria is the optimum condition for purification. The rôle of protozoa is to keep the bacterial numbers limited. This viewpoint is somewhat similar to that which was later maintained by Purdy and Butterfield.

In line with Wagner's work it was thought of interest to study the effect of certain chemicals on the protozoa and bacteria and the purification of sewage in the presence of activated sludge.

Method

Activated sludge obtained from Madison-Chatham, N. J., and screened sewage from Plainfield, N. J., were mixed on the basis of 25 per cent of sludge by volume. The mixture was treated with different chemicals and aerated for six hours in tall glass tubes fitted with porous plates. Bacterial counts, and numbers and types of protozoa, were determined on the sludge mixture before treatment and before and after aeration. The B. O. D. of the supernatant liquor after $^1/_2$-hour sedimentation was determined before and after aeration. When the sludge mixture was sterilized, as in the case with chlorine treatment, the excess chlorine was neutralized with sodium thiosulphate and reseeded with 1.0 per cent of sewage.

Results

The results of treatment with potassium cyanide and toluene are given in Table I.

TABLE I

BACTERIA AND BEHAVIOR OF PROTOZOA

Before and after Aeration for Six Hours in Presence of Sewage and 25 Per Cent of Activated Sludge

Treatment	Concentration	B. O. D. Before, P. p. m.	B. O. D. After, P. p. m.	Bacteria* Before Thousands per Cc.	Bacteria* After. Thousands per Cc.	Protozoa
KCN	1:2500	71	145	165	2450	No sign of movement
Toluene	Vapors passed through mixture for 30 min.	335	12	365	2500	Only 3 types active after $^1/_2$ hr. aeration. After 1 hr. aeration only *Lembus* and *Trepomonas* not observed, numbers of small flagellates much reduced

* Bacteria in untreated sludge mixture 280,000 per cc.

It will be seen from the results that potassium cyanide in the concentration used reduced the bacterial numbers initially but after six hours of aeration the numbers were higher than in the untreated sludge. At the end of the aeration period the KCN had also stopped all signs of protozoan movement. The B. O. D. of the supernatant liquid had been doubled as a result of the treatment.

Toluene vapors passed through the sludge mixture for 30 minutes stimulated bacterial numbers, but different types of protozoa were affected differently. After one-half hour aeration only three types of organisms were active, namely, monads, amoebae and *Vahlkampfia albida*. *Opercularia* were extremely vacuolated but appeared to be living. After an hour's aeration only *Lembus* and *Trepomonas* had apparently disappeared, although the numbers of small flagellates were very much reduced. *Opercularia* had resumed their activity. An examination of the sludge the following day showed that the protozoa were fewer, both in genera and numbers, than in the original sludge. Thus toluene had a temporary drugging effect on the protozoa. The purification as measured by B. O. D. reduction was very efficient (96 per cent).

Results following the application of chlorine are shown in Table II. The

TABLE II

Treatment	Concentration, P. p. m.	Residual after 10 Min., P. p. m.	Organisms	B. O. D. Before Aeration, P. p. m.	B. O. D. After Aeration, P. p. m.	Increase, Per Cent
Chlorine	105	More than 1 p. p. m.	All killed	250	330	32
Chlorine	80	More than 1 p. p. m.	All killed	150	230	53

application of chlorine to the activated-sludge mixture to give a residual of 1 p. p. m. with orthotolidine considerably increased the B. O. D. of the supernatant after 5 hours of aeration (32 to 53 per cent).

Discussion

As was indicated above, it is difficult to arrive at conclusions regarding the possible rôle of protozoa and bacteria in the activated-sludge process based on experiments comprising the addition of chemicals, for the following reasons:

1. The effect of the chemical is not limited to the protozoa alone, but the bacteria are also affected.
2. Not all types of protozoa are affected similarly. Some are inactivated temporarily, some are not affected at all, while others are destroyed.
3. The chemical has an effect on the physical character of the organic matter.

It is generally known that the activated-sludge floc is a very sensitive and loosely held conglomerate of organic matter, and that a slight disturbance will break up this mass. It was observed with these chemicals that, irrespective of the turbidity of the supernatant liquid after aeration, there was left in the aerated supernatant liquor, after one-half hour settling, a great number of fine "pin-point" flocs. This was especially the case with chlorine and potassium cyanide. Therefore the effect of these chemicals on the purification, as measured by B. O. D. values of the supernatant liquor, was due primarily to the deflocculation of the activated-sludge

particles. In view of this fact it is difficult to evaluate properly the changes produced in the flora and fauna by the addition of the chemicals, and their possible rôles in purification.

The stimulation of bacterial numbers by potassium cyanide and toluene can be attributed to the deleterious effect of these chemicals on protozoa. It is a generally known fact that, when the protozoa are inactive, bacterial numbers increase. In our experiments, however, increased purification was not obtained by increased bacterial population. Wagner's contention that high bacterial numbers do not necessarily indicate better purification by the activated-sludge process would seem to be borne out.

It is also true that protozoa limit the bacterial number by feeding on them. But whether the feeding of the protozoa on the bacteria is of significance in the purification process is another question. It is difficult to see how the conversion of bacterial protoplasm into protoplasm of protozoa, *per se*, will produce any material effect on purification. It is true that during this process of assimilation bacterial protoplasm is digested, oxidized and stabilized, part of it is converted into CO_2 and a part is assimilated into the protoplasm of the protozoa. However, the concentration of bacterial cells, in comparison with the organic matter of the sewage, is so small that the purification effected by the removal of bacteria by protozoa can be but a minor factor. A more reasonable theory, as Purdy and Butterfield have indicated, is that under given conditions of food and environment bacterial density reaches a maximum value in a relatively short time, after which little proliferation takes place. The feeding of protozoa on bacteria under these conditions will stimulate bacterial proliferation and maintain the process of purification by bacteria.

Aside from these considerations Wagner has overlooked, in his experiments, the effect of the chemical treatment on the state of division of the colloidal aggregates. It is true that he did not use any activated sludge, but the flocculation even of the sewage colloids may be prevented as a result of the chemical treatment.

In a similar way sodium chlorate used by Cramer[4] may have a physical effect on the colloidal material, causing "clarification." A concentration of 0.3%, or 3000 p. p. m., is far higher than the amounts of any coagulants used for sewage coagulation. The reduction of bacterial numbers in the supernatant liquor of the sewage treated with sodium chlorate may also be explained on the basis of partial sterilizing action of the chemical rather than clarification effect. If this is the case then it becomes clear why the treated sewage did not become septic. Cramer's results with partial sterilization by heat (60° C. for 30 minutes) are probably also affected, since this temperature kills not only protozoa but the majority of non-spore-forming bacteria.

The inoculation with sewage bacteria and yeasts of heat-sterilized sewage

treated with sodium chlorate, which resulted in failure to produce clarification or septicity, as reported by Cramer, is not convincing because of random selection of bacteria and the possibility of having missed the essential types. The addition of sodium chlorate to heat-sterilized sewage, according to Cramer, did not produce clarification. This is difficult to interpret in the absence of more definite expressions of the degree of clarification. The term clarification has been used in the article as an "all or none" property rather than a matter of degree. However, in spite of the criticisms, Cramer's article is stimulating of thought.

Conclusions

The method of study employed by several investigators in evaluating the rôle of protozoa and bacteria in purification of sewage by the activated-sludge process—namely, by addition of chemicals and heat—is fraught with difficulties because of the secondary effect of the chemical on the physical state of the activated-sludge floc. Some of the chemicals may tend to flocculate while others deflocculate causing errors in interpretation if the effects are attributed mainly to the selective action of the chemical on the flora and fauna.

In our experiments the inhibition of the protozoan activity, either by potassium cyanide or toluene, resulted in increased bacterial numbers. Flocculation was increased or decreased, dependent upon the chemical used, accompanied by greater or less degree of purification as measured by B. O. D. reduction. Chlorine added until a residual was obtained similarly increased the B. O. D. of the supernatant liquor.

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Removal of Grease and Oils from Sewage by the Imhoff Method*

BY WM. A. ALLEN**

It has long been recognized that the oils and grease wastes which are emptied into the sanitary sewers, whether intentionally or unintentionally, constitute a very annoying problem for the sewage works operator.

At the Pasadena plant, this feature has been given considerable thought since the plant was first placed in operation. Various schemes for the collection of the scum formed were tried in the influent troughs, aeration tanks and clarifier feed-troughs. All of these methods required considerable labor for skimming and served only as a cure for the existing condition instead of eliminating the cause. As early as 1925–26, several experimental grease traps were constructed in an effort to remove the grease before it reached the aeration tanks. While some removal was effected, the type of skimming tank did not seem quite practical for large-scale operation.

During the spring meeting of the California Sewage Works Association in 1929 at Fresno, a general idea of the method used by Karl Imhoff was given us by C. G. Hyde. We started construction of an experimental tank based on the information obtained. This tank was so arranged that it connected as a part of the regular operation instead of separately as an experimental unit, as we wanted to observe the results under normal conditions.

The tank as constructed is rectangular in shape, 10 by 32 ft., with an effective depth of 3 ft. Norton porous plates, 1 by 2 by 12 in., are used for aeration. These are arranged in three plate-holders of our own design, each holder containing 10 plates. They are placed along the wall of the flowing-through side. A floating redwood baffle, 4 in. wide by 10 in. deep, with triangular blocks set on top, is used as a retainer for the grease collected. The baffle is approximately along the center line of the tank. The blocks on top of the baffle are so placed that, in plan, a triangular opening is made, feeding into the grease collection side, the opening on the flowing-through side being 4 in., tapering to 1 in. on the collection side.

The aeration of the sewage partly emulsifies the oils and greases, so that when thrown over in back of the baffle, a light scum is formed which collects on the surface and is held in the collection compartment by the baffle and the cross-flow action caused by aeration. The sewage flow from the tank passes under the concrete wall at the discharge end into a concrete flume and then into the influent trough to the aeration tanks.

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From the start very good results have been obtained on grease removal. As stated, this unit was intended as an experiment. Its use so far has more than justified the expense of construction. We intend to enlarge the skimming tank to at least double the present size, in order to obtain a greater removal of grease from the sewage. The enlarged unit will have about 3 min. detention, as recommended by Imhoff. The present unit has 1.3 min. detention, which is apparently nearly sufficient to remove the ordinary greases contained in the sewage, but not large enough to care for the excess oils. Since using the skimming tank, there is a noticeable improvement in the amount of grease scum appearing on the surface of the aeration tanks. There are times when unusually large quantities reach the plant with the sewage, and, due to lack of capacity, some of the oil passes into the aeration tanks, resulting in incomplete aeration and a lower standard of clarification.

The oils received on these occasions are usually fuel oil, or waste oils from garages and machine shops. The practice of emptying these oils into the sanitary sewer is prohibited by city ordinance, but Saturday night seems an excellent time for someone to disobey the law. By close coöperation with the inspection departments of the contributing cities, instances of this kind are kept down fairly well.

The average removal from the skimming tank is about 20 cu. ft. of scum daily. This scum is removed by hand skimming and dump trucks, and buried in trenches with the screenings from the Dorr screens.

A partial analysis of the scum shows the following:

Loss on evaporation	84.22%
Loss on ignition	13.78%
Ash	2.00%
	100.00%
Oils and fats	24.50%

Anyone familiar with the activated-sludge process of treatment can readily appreciate that the removal of this much grease is a decided advantage to aeration and clarification.

Prior to using the grease-skimming tank, it was often necessary to employ an extra crew of 4 to 10 laborers to skim the grease scum off the aeration tanks after a large quantity of oil reached the plant. It usually required several days to accomplish this and the effect was noticeable for several days thereafter.

An estimate of the cost of grease skimming prior to the construction of the skimming tank is $1200 to $1500 per year. Since using the tank, this expense has been eliminated, our own crew being able to care for any skimming still necessary.

We now find the grease situation fairly easy to cope with, and after en-

larging the grease tank, we expect very little difficulty from grease. It is still contended, however, that the most efficient and economical method of grease removal is at the source. If we can eliminate the cause, no remedy is required. This angle of the situation is, I believe, very important and should receive equally as much attention as how to dispose of the grease and oils after they reach the treatment plant.

Los Angeles Method of Grease Removal*

BY G. A. PARKES**

The city of Los Angeles disposes of its sewage by dilution into the Pacific Ocean at a point about the middle of Santa Monica Bay. The sewage, before being discharged into the ocean, is passed through fine screens of the Dorrco type, which have slots $^1/_{16}$ by 2 in. Any solid or liquid matter which will pass through these slots goes out to sea without further treatment, while the solid material rejected by the screens is removed and buried.

Some time ago it became apparent that oil and grease which were occurring in increasing quantities in the sewage were causing trouble by blinding the screens, and increasing the cost of maintenance. The oil and grease which did not stick to the screens passed through with the sewage and eventually found its way back to the beach in the vicinity of the outfall and caused objectionable deposits on the sand.

Accordingly studies were undertaken to eliminate these greases and an extensive series of experiments was performed. Various systems of grease removal were considered, including the Imhoff method, and several series of tests were carried out to determine the relative merits of grease removal before and after screening. Without going into detail it may be stated that grease removal, before screening, proved to be much more effective and that the Imhoff design of grease removal tank did not prove to be as efficient as our own. In all such comparative tests every effort was made to operate the different designs on the same bases, so that results would be truly comparable. All conclusions were based on the results of careful sampling and the analysis of many samples. Several interesting points were noted in connection with this sampling and analysis and it became apparent that the usual methods used were not always applicable.

A complete description of all the work done during these tests, which lasted in all about a year and a half, would be quite voluminous, so the present paper will be confined to the design which seemed to give the most satisfactory results and which will probably be used if a full-sized grease-removal plant is to be installed.

Sedimentation in any form is not at this time contemplated in connection with sewage disposal at Hyperion, so that the grease-removal problem was attacked from the angle of flotation only, with the assumption that the heavier solid matters should be carried on into the screening plant to be removed by the fine screens.

* *Presented before Third Annual Meeting of the California Sewage Works Association, Long Beach, Oct. 9, 1930. Reprinted from the California Sewage Works Journal, Vol. III (1930).*

** *Assistant Engineer, Bureau of Engineering, City of Los Angeles.*

It was found that aeration aided greatly in the flotation of the greases and oils and that by proper control a thick tenacious scum could be formed, which could be easily removed from the surface of the sewage. Experiments showed that a tank designed with a relatively flat bottom slope—not over 40 deg. from the horizontal—could be used if the retention period in the tank were short enough to prevent the deposition of lighter solids.

The accompanying diagram shows the approximate proportions of the tank design which proved to be most satisfactory during the recently completed experiments, which were made on quantities of sewage as high as 6.67 cu. ft. per sec. The inlet channel at the left is rectangular and of proper size to give a velocity of at least 2.5 ft. per sec. It is in this channel that the aeration is applied by a diffused-air system of our own design. The aeration channel flares to the full width of the tank between points *B* and *C*, and at *C* the width of the tank is approximately one-third the length, *C–D*. At the point *C* the inlet velocity is less than 0.5 ft. per sec. at maxi-

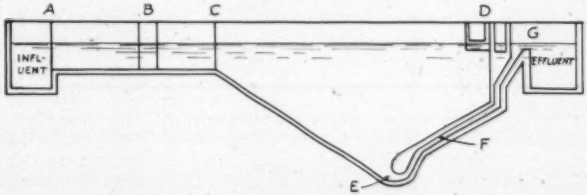


Diagram of Los Angeles Type Grease Skimmer.

mum flow, and decreases rapidly in moving forward into the tank. The air quickly brings the grease and oils to the surface and forms the scum already mentioned, which collects on the surface of the sewage at the left. Here it is removed by a Link-Belt scraper at *D* and carried to a smaller concentrating tank, not shown. The sewage passes downward and out through a carefully formed outlet slot, *E*, extending across the tank into the outlet passage *F*, where a velocity of 3 to 4 ft. per sec. is maintained. The sewage finally leaves the tank over an adjustable weir, *G*, which maintains the sewage at the optimum level.

The method of aeration used consists of discharging small streams of screened sewage at high velocity into the sewage in the aeration channel. These high-pressure nozzles are spaced 2 in. above the surface of the sewage, and in passing through this 2-in. space each fast-moving stream of water carries a large volume of air by surface friction into the sewage body. This system introduces the air into the sewage in very fine form, and while fairly high in cost, is simple in operation and far more effective in removal of grease than any of the types of aeration now in use.

The tank is designed for brief retention periods, from 2 to 3 min. being found most satisfactory. Longer periods did not produce increased efficiencies, but did permit the deposition of greater quantities of sludge.

Investigation showed that combined or saponified greases and fatty acids were not objectionable from the standpoints of screen maintenance or beach pollution, but that free or uncombined oils and greases were objectionable from both standpoints. Consequently, all results were considered on the basis of the removal of free greases and oils, although the available methods of grease analysis probably do not give a true measure of such material present in the sewage and the results probably err on the side of safety.

Removals of 50 to 75 per cent of the free grease were obtained with the design shown, which on a full-size basis would be the equivalent of 4 to 6 tons of pure free grease and oil per day. Such material would not be removed in pure form, but would probably amount to 21,000 or even 30,000 gal. per day of greasy material, removed in the form of scum and containing much water, rubbish, and other floating matter.

The cost of removing grease by this method in a large installation has been roughly estimated at 15 to 30 cents per million gallons, including power and labor but not capital charges. The cost of constructing such a full-size plant has not yet been fully determined.

The grease and oil so removed has little or no commercial value on account of impurities, but may be burned in a properly designed furnace.

The city of Los Angeles is considering the installation of a full-size plant of the above design to treat the entire flow of sewage at Hyperion.

Sewage Works Operation

The Administration of Sewage Treatment Plants from the Viewpoint of the Visitor*

By Walter A. Sperry**

Water works have always been as attractively built show places as the local community could afford. Where can you find any plant so poor as not to have a patch of lawn and at least one flower bed? For years water works have been visited, inspected and admired, especially in these modern days of filter plants and softening works. Scarcely ever do they lack funds or have a budget problem and bond issues for enlargements seldom fail to win a "yes" vote.

It has been a different story for sewage treatment plants. The public has not been so interested in its "used water supply." Plants well designed in the beginning have operated poorly and have deteriorated rapidly for want of funds. Ask any sad-eyed, discouraged assistant engineer in charge of sewage disposal in any state department of health in any state to tell you his story. Because sewage works are non-revenue producing, isolated, down-stream, far away and unpleasant or difficult to approach, their budgets have been ruthlessly cut despite the sanest of pleas.

All this is rapidly changing. What has been of interest to officials only is rapidly becoming of interest to the layman. Time for recreation, interest in the out-of-doors, wide-spreading highway systems, easy and cheap transportation for the family group, Isaac Walton Leagues, Boy Scouts, Camp Fire Girls, Conservation Departments and Health Divisions are all having a share in this awakening interest.

Forty-five tons of sewage solids per 1000 persons per year discharged direct to the river is beginning to have a new and sinister meaning. Its relation to observed river conditions is being brought home to Mr. Average Citizen.

Laws for the financing of sewage treatment works are being made increasingly more favorable and sewage rental laws or operation on a utility basis through charges based upon the water meter readings under either public or private ownership, are now practical. Courts in some states may empower city officials to issue bonds over the vetoing vote of its people and borrowing on the plant and its revenues as security is being made possible.

* *Presented before the Fourth Annual Meeting of the Central States Sewage Works Association, Madison, Wis., May 22, 1931.*

** *Superintendent, Aurora (Ill.) Sanitary District.*

All this is putting sewage treatment in a new light. Operation as a utility, rendering service as other utilities, where the individual may pay for disposal of his own share of wastes on an equitable basis, creates revenues and therefore an operating fund that is a direct tax for a direct service rendered. By these means the old budget problem is removed. Bypasses may be closed and Mr. Citizen begins to want to "nose" about the sewage plant to see what manner of service he is getting for his money.

After all, the plant belongs to him. He is a stockholder therein. His dividends are represented by the most efficient disposal of his refuse that his particular plant will afford. He not only ought to want to know what it is all about—he has every right to demand to be shown.

The modern sewage treatment plant when operated as a utility is not likely to be the unwanted child (often forced by law) and a new drain on the city family's purse, as it formerly was. Public interest and local pride are awakened in the undertaking. Modern methods tend to make the plant more attractive and more favorably situated. Time and effort, also moderate expenditure of funds, may be spent for appearances of buildings and grounds, for the public has become interested.

It was the deliberate attempt, in building the million-and-a-half dollar sewage disposal plant at Grand Rapids, Michigan, recently put into operation, to make the whole undertaking as attractive and popular as the water works, long a by-word in that city. In its finished state it will be more so.

Why not? Its work is fundamentally important to the health and well-being of many more people than the population which the water supply serves. It preserves the decent self-respect of the community. Its processes are more complex than those of water purifications and its operating details, if anything, are more spectacular.

It is not only good business policy on the part of officials to plan attractive sewage treatment works but emphatically a public duty as well. The need for such plants to the individual community can never diminish and must increase. Moreover, time will require necessary refinements in the quality of effluent as cities grow and pollution loads increase. The public will demand increasing measures of service once it is realized what can be done, just as surely as, step by step, it has demanded a more and more perfect water supply as tools and methods permitted. There was first the bug-free water and the elimination of typhoid fever. Chlorine tastes were endured. Then softened water bug-free, then bug-free softened water without taste, and now all this plus super-softening. Some cities have all these refinements. Other cities can also have them if the public demand is strong enough.

Since sewage treatment is here as a permanent necessity, it must be

as permanently and satisfactorily financed. It is imperative, therefore, that every effort be made to inform and enlighten the citizen stockholder who must pay the bills. His attention must be caught, his intelligence appealed to and his favorable opinion sought. The same local pride must be attached in his mind to the sewage disposal plant as has always existed for the water works.

Plant superintendents will do well, then, to consider the visitor. It is

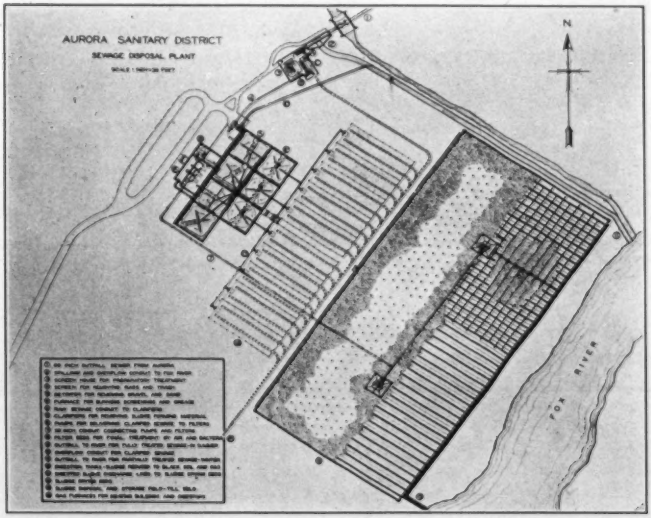


FIG. 1.—A Picturized Plan Drawing of the Plant, Partly in Water Color, with an Explanatory Legend Naming the Plant's Parts. This Drawing Is 36 by 42 Inches and Is Framed.

firmly believed that there is a permanent need for trained superintendents who not only know their plants but are able to make them known to others. This includes the ability to speak in public, the art of picture-clear explanation and a small genius for charting and diagramming.

These qualities were brought home to the speaker in 1912 when putting into operation a new water filtration plant. It was necessary to win favorably a large portion of Dutch residents, whose habits of mind are naturally conservative, and to get them not only to accept a river-water

supply in lieu of private wells, but also to use that supply after treatment with chemicals. It was accomplished by the general methods proposed in this paper. The filter plant was heralded as that city's most outstanding achievement and so stood till 1930, when the sewage disposal plant competed for the public's attention by the continuation of a similar educational policy.

The fundamental psychology underlying this approach to the visitor is that he fears and criticizes that which he does not understand. It is axiomatic among public officials that the less a man knows the more he

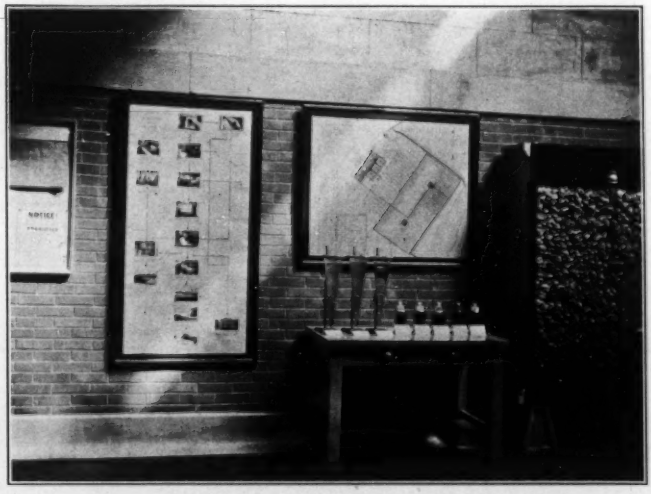


FIG. 2.—A Table Containing Three Imhoff Cones for Typical Samples of Raw and Settled Sewage and Filter Effluent, Also Pint Sized, Glass-Stoppered Sample Bottles for Samples of Screenings, Grit, Grease Skimmings, Digested Sludge and Dried Sludge, All Appropriately Labeled.

kicks. If the visitor has been courteously received and given time for a brief but illuminating trip through the plant, understanding replaces fear and facts supplant conjecture. He leaves the plant with admiration for its processes, faith in and respect for its officials and an understanding patience when things go wrong.

Instruction of Visitors at Aurora.—The Aurora Treatment Plant, located on a main highway, is ideally situated and designed to appeal to

the visitor. It possesses attractive buildings, placed in a setting of natural trees and rolling ground on a beautiful stretch of the Fox River. Its general appearance is peculiarly inviting. It is the specific purpose of this paper to detail the plans adopted for the reception of visitors at the Aurora plant as a concrete example.

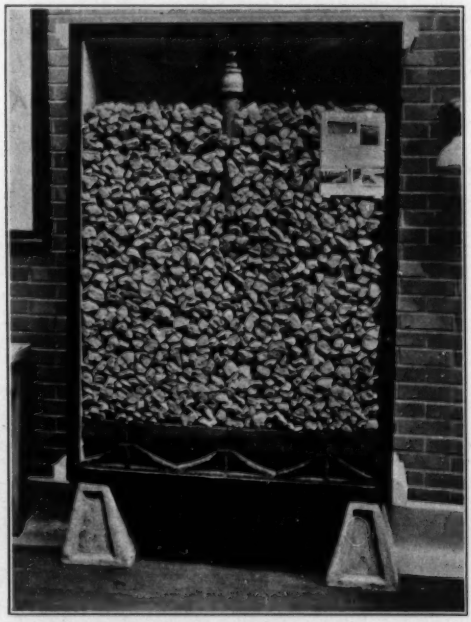


FIG. 3.—A Filter Model, Faced with Plate-Glass, Approximately 45 In. Wide, 65 In. High and 15 In. Deep, Made Up of the Typical Underdrain Tile, Crushed Stone and Filter Nozzle and Piping. On the Face of This Model Are Typical Photographs and Notes Showing the Filters in Operation.

The following schedule was prepared in 1931:

A.—A well-designed road sign on the highway at the main entrance, of such dimension and letter size as to be easily read, naming the plant and its ownership and announcing that visitors are welcome.

B.—A declaration of policy under the bronze tablet in the main entrance to the buildings. Detailed thus:

TO THE VISITOR:

The Trustees welcome you as a visitor to this—YOUR—plant.

You are free to go about and inspect its working.

It is suggested that you first examine the general exhibit prepared for your instruction on the pump room floor.

After this you will find statements in each part of the plant explaining that portion.

WALTER A. SPERRY, *Supt. of Plant*

C.—A group of exhibits planned to explain and instruct. This was placed on the main pump room floor where plenty of space was available

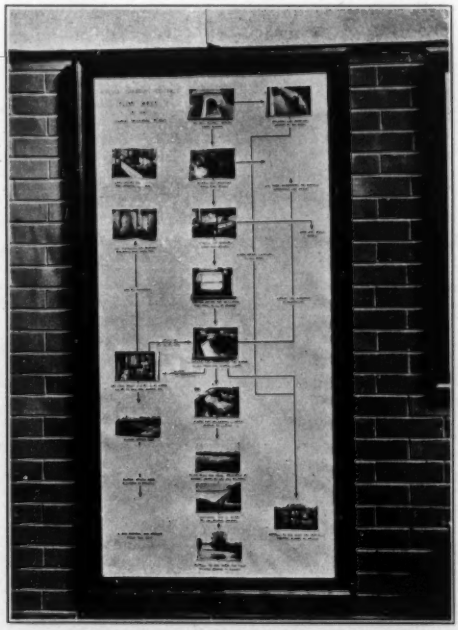


FIG. 4.—An Illustrated Flow Diagram of the Plant, Combined with a Complete Set of Pictures to Visualize the Diagram, Approximately 27 In. by 60 In. and Framed.

for accommodating a group of at least 40 people, and railed in to afford protection from the motors. Its make-up can be varied according to the ingenuity and purse of the local plant. This particular group at present is made up of the following items:

1. A special picturized plan drawing of the plant partly in water color with an explanatory legend naming the plant's parts. This drawing is 36 by 42 inches and is framed (Figure 1).

2. A table beneath containing three Imhoff cones for typical samples of raw and settled sewage and filter effluent, also pint-sized, glass-stoppered sample bottles for samples of screenings, grit, grease skimmings, digested sludge and dried sludge—all appropriately labeled (Figure 2).

3. A filter model faced with plate glass approximately 45 in. wide, 65 in. high and 15 in. deep, made up of the typical underdrain tile, crushed stone and filter nozzle and piping. On the face of this model are explanatory notes and typical photographs showing the filters in operation (Figure 3).

4. An illustrated flow diagram of the plant combined with a complete set of pictures to visualize the diagram, approximately 27 in. by 60 in. and framed (Figure 4).

5. A large bulletin board for posting the monthly plant records and for miscellaneous notes and striking-contrast data in number or curve form.

D.—A series of framed statements placed around the plant explaining the function of that particular portion and detailed as follows:

THIS IS THE SCREEN HOUSE:

Sewage prepared for treatment here.

Rags and trash are removed by a bar screen.

Grit, sand and gravel are removed by a shallow basin with a rotating plow and a mechanical rake that dries and delivers it.

Grease and skimmings from the clarifiers also delivered to this building.

The grit is buried. The grease and screenings are burned in a plant gas fired incinerator.

FURNACE ROOM:

These furnaces burn the gas generated by the bacteria working on the solids, in the digestors, removed from the sewage in the clarifiers.

About 30,000 cubic feet of gas is produced daily.

It has about 25 per cent more heating value than the Aurora city gas.

These furnaces provide heat for the buildings and keep the digestors hot.

The surplus gas is used in the laboratory and to operate the incinerator.

VENTURI METER:

This instrument is connected to a special double cone-shaped pipe in the main sewage conduit.

It measures and records, accurately, the total volume of sewage flowing for every hour of the day.

PUMPING STATION:

The pumps in this room deliver the *clarified* sewage liquor from the clarifiers to the filter beds for final treatment before discharge to the Fox River.

They are used for summer time operation only, when the river is low, the water warm and less oxygen is available.

Two pumps deliver at the rate of 8 million gallons per day and one at the rate of 6 million gallons per day.

They are driven by two 75 horse-power and one 50 horse-power motors.

CLARIFIER HOUSE:

The clarifier house is the "heart" of the plant.

Here the "sludge-bank" forming solids are separated from the sewage liquor.

About 75 per cent of the settleable solids are deposited here during a settling period of about 2.5 hours.

These clarifiers are 50 feet square and 10 feet deep. The sludge is concentrated on their cone-shaped bottoms at the center by plows carried by the slow moving bridge and pumped to the digestors by a special sludge pump.

The sewage liquor flows directly to the river in the winter time and to the pump wells for delivery to the filter beds in the summer time.

DIGESTOR HOUSE:

The digestors are three in number. Each is 50 feet square and 16 feet deep. They are equipped with hot water coils, stirring paddles and a sealed gas collecting cover.

The sewage solids, collected daily in the clarifiers, are stored here for a period of weeks during which time the organic matter is broken down into about 30,000 cubic feet of gas per day and a garden soil of moderate nitrogen content.

FILTER BEDS:

The clarified sewage liquor, in the summer time, must have its appetite for oxygen reduced through the filters before discharge to the river.

This is accomplished by spraying the sewage in thin films for close contact with sunlight and the oxygen of the air after which it trickles over the 6 feet of crushed stone, on the surface of which grow "jelly-like" films whose bacterial content feed upon the organic content of the sewage. This so reduces its oxygen demand as that it can do no harm to the fish or plant life of the river.

These beds measure 273 by 586 feet and cover 3.6 acres. They are divided into 4 areas. The sewage is applied intermittently by two syphon-controlled dosing chambers on top of the filters. The filter material is crushed stone, passing a 2-inch ring, which rests upon a special tile floor whose channels discharge the finally purified sewage to the collecting channel along the east side.

SLUDGE DRYING BEDS:

The sludge drying beds are tile underdrained and sanded areas for receiving the wet digested sludge from the digestors till dry enough to be removed for storage or sale.

They are 10 in number, and each 40 by 125 feet in area. They are equipped with an industrial railway system.

Sludge when dry enough for removal contains about 40 to 50 per cent moisture and is about 4 to 6 inches deep on the beds.

This dried sludge is without odor and contains about 2 per cent of nitrogen. It is well adapted to any garden or lawn use.

E.—Appropriate labels on certain doors, such as those to the clarifier house and furnace room, through which the visitor might hesitate to pass.

F.—A neat gray work suit for Sunday wear by the plant operators, after the general morning clean-up.

G.—A leaflet, soon to be prepared, illustrated with at least the picture plan and the flow diagram and containing a simple explanation of the principle of the process and its application to the plant, also selected data. This leaflet to be used as a guide in going about the plant and for file or souvenir purposes.

H.—Walks for easy and inviting access to the effluent side of the filters at the river so that the visitor may *see* the final results accomplished.

The Handling of Groups.—The handling of groups, especially school classes, requires special technique. School children are the citizens and taxpayers of tomorrow, therefore care and thought should be given to their visits.

The following well-considered plan of procedure is recommended.

A.—A short lecture. This gives control of the group by converting it from a lark to a real inspection trip. It lends dignity to the occasion, catches their attention and instructs them in the things they came out to see. Such a lecture should define sewage—give its meaning in terms of total solids discharged to the stream—discuss the natural forces at work in a stream with particular application to the effluent discharged from the plant. This is followed by a brief pre-view of the things they are about to see. The class will now be under control and with a gratifying anticipation of the trip ahead.

B.—The trip through the plant should parallel as closely as possible the route of sewage flow in order to avoid confusion in applying the lecture. During the trip, special care should be taken to show the group the raw incoming sewage in order to contrast it with the final effluent. This helps to give visual and spectacular emphasis to the effectiveness of the plant's work. For the same reason it is necessary to point out carefully the influent and effluent side of the settling tanks to emphasize the separation of the solids from the liquids and the relation to the removal of sludge-bank forming material.

C.—At several points where the class can be gathered together a two- or three-minute recapitulation should be given for the benefit of the laggard and backward. This tends to clarify their thinking—holds attention and creates opportunity for questions.

The General Plant Appearance.—The same law that urges any housewife into an orgy of cleaning as a preliminary to the reception of visitors

applies to sewage plants. It is inevitable that cleanliness and reasonable sanitary conditions must become the usual order about a sewage plant. The things to be done will be governed by the type of plant but this includes attention to such out-of-door details as: neat flower beds; trimmed lawns; driveways and walks free from weeds, properly edged and dust laid; tools in order; apparatus appropriately painted.

Indoor details include: freedom from odors; good ventilation; general cleanliness and order; dust and cobwebs under control; frequent hosing where appropriate; reasonable use of paint and whitewash; clean around door knobs and frames.

At Grand Rapids, Michigan, the visitors' program includes careful removal of floating material from the settling tank surfaces on Sunday. At DeKalb, Illinois, the program includes the exhibition of fish living in the effluent liquor as an indication of the purification accomplished. At Cleveland, G. T. Pond is making excellent use of graphs for displaying plant data. At Aurora we believe the men's appearance should be in keeping with that of the plant on Sundays. The men are required to be shaved, have clean shirts and wear an appropriate type of wash suit and they are trained to conduct the visitors through the plant.

These suggestions by no means exhaust the list of things to do to attract the visitor. They are suggestions only of what can be done. If done, the writer is convinced that no similar effort in any other undertaking about the plant will return such enduring and valuable dividends, to the plant, its trustees, superintendent or to the community served, as a well-planned visitors' program.

Sludge Drying Beds*

BY JOHN F SKINNER**

Covered or not covered sludge beds—that is the question. It will be interesting to have the views of operators who have used both types. The admitted advantages of the two types of beds are:

For Open Beds: Less construction cost per unit of area; no maintenance cost of a fragile superstructure; no operating cost for artificial heat; no insurance.

For Covered Beds: Less area per capita, hence greater capacity where space is limited; more frequent drawings due to protection from inclement weather; less chance of nuisance if the sludge is not properly digested; better appearance, if close to dwellings.

Some of the alleged advantages about which there are differences of opinion, and which may actually differ in different localities and under different conditions, are: relative cost per capita of construction, maintenance and operation; relative areas required; value of different types of ventilation; value of artificial heat and ventilation.

The State of New York requires in its present rules the following areas for open and covered beds which are based upon the experience of Mr. Holmquist's Division:

TABLE I

SLUDGE BED AREA REQUIREMENTS OF N. Y. STATE DEPARTMENT OF HEALTH

Preliminary Treatment	Square Ft. per Capita Open	Covered
Plain settling, less than 5 hrs.	5.0	2.5
Plain settling, greater than 8 hrs.	3.0	1.5
Two-story tanks	1.0	0.5
Separate digestion tanks	1.5	0.75
Secondary or final settling tanks	0.5	0.25

Seven plants with which the speaker is particularly acquainted, and six of which he designed, have sludge beds as shown in Table II. Costs include excavation, concrete, steel, clay puddle, broken stone, sand and gravel, fine-screened sand, cinders and drainage tile.

Several facts pertinent to the subject may be noted:

With one exception the plants are all within a radius of six miles.
They were constructed at various times during the last 16 years.
The populations served ranged from 4200 to 200,000.
The average area of bed is less than 0.4 sq. ft. per capita.

* *Presented before the Spring Meeting of the New York State Sewage Works Association, Freeport, Long Island, June 5, 1931.*

** *Consulting Engineer, Rochester, N. Y.*

The costs vary with the cost of materials and labor as instanced by duplicate constructions of the Brighton plant 12 years apart, where the second beds cost over $2^1/_2$ times the first.

In the cases of East Rochester and Summerville, beds of similar design, constructed by the same contractor, cost nearly twice as much at the smaller plant.

There is also some difference in the design of the beds as indicated.

The cost of open beds may, for the purpose of this discussion, be taken at from $0.50 to $1.00 per square foot with an average of $0.75. The cost of glass-overs as received from four manufacturers runs from $0.75 to $2.00 for standard plain construction, including gable ends, sides, windows and doors, and may be assumed at an average of $1.50 per square foot, or twice the cost of the remainder of the bed. If covered beds are three times as expensive as open beds, one might expect of them three times as many fillings per year, or in other words, one-third the area. Probably Mr. Holmquist's ratio of 2 to 1 is more nearly correct.

The records of the Irondequoit plant are instructive as they represent uninterrupted operation of a large plant for 13 years (Figures 1 and 2).

The plant was projected for a population of 400,000. One-half of it was constructed and this is now 50 per cent overloaded. In 1930 we had 48,000,000 gallons per day passing through the tanks with a detention of 44 minutes. As the tanks are preceded by six efficient grit chambers 90 ft. long, and six fine screens of the Reinsch-Wurl disc type with $^1/_8 \times 2$ in. openings, the fine suspended solids deposited in the tanks amount to but 44 p. p. m. Approximately one-third of this sludge is la-

TABLE II

COST OF OPEN SLUDGE BEDS CONSTRUCTED 1915–1930

Name and Location of Plant	Year Built	Design Population	Area of Beds Sq. Ft. Total	Area of Beds Sq. Ft. Per Capita	Cost of Beds Total	Cost of Beds Per Capita	Per Sq. Ft.	Depth of Fine Porous Material
Brighton District, Rochester, N. Y.	1915	10,000	3,360	0.34	$ 1,043	$ 0.10	$ 0.31	6″
Irondequoit Plant, Rochester, N. Y.	1916	200,000	77,440	0.39	54,000	0.27	0.70*	13″
Charlotte Plant, Rochester, N. Y.	1920	10,000	3,754	0.38	3,745	0.38	1.13*	6″
Brighton District, Rochester, N. Y.	1927	10,000	3,360	0.34	2,674	0.27	0.80	6″
Village Plant, East Rochester, N. Y.	1929	10,000	3,858	0.39	2,219	0.22	0.58	18″
Village Plant, Albion, N. Y.	1929	5,000	1.00		1,351	0.27	0.27†	6″
Summerville District, near Rochester, N. Y.	1930	4,200	2,100	0.50	2,172	0.52	1.03	12″

* Large amount of concrete.

† No concrete.

gooned while the other two-thirds, the sludge settled from 32,000,000 gallons per day, the sewage of 200,000 people, is dried on 40 beds, each 44 feet square, giving a total of 77,440 square feet of open beds. These sludge beds, with an area of 0.39 sq. ft. per capita, have handled the sludge. If three times the detention period were provided, we might expect double the amount of sludge and require double the area, or about 0.8 sq. ft. per capita.

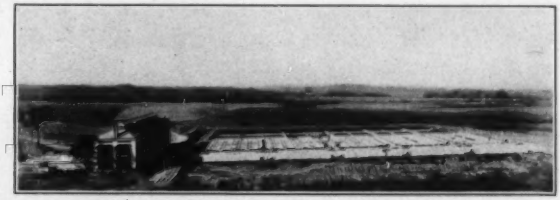


FIG. 1.—Irondequoit Plant—Rochester, N. Y.

The Irondequoit plant at Rochester is subject to rain, snow and sleet, as it is on the shore of Lake Ontario, but records of air temperature at the plant average 1.6° F. higher than those of New York State and precipitation is 5.30 inches less, as exhibited in Table III.

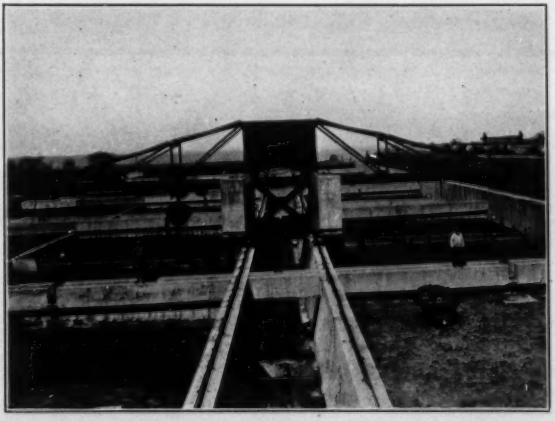


FIG. 2.—Irondequoit Plant—Rochester, N. Y., Sludge Beds.

TABLE III

METEOROLOGICAL DATA

U. S. Weather Bureau	Rochester	Mean for N. Y. State
Mean temperature, ° F.	47.5	45.9 (54 stations)
Mean precipitation, in.	33.28	38.58 (129 stations)
Average number of days with 0.01 in. precipitation (Apr.–Nov.)	97	.....
Average number of days (20 years) with 0.10 in.	50	.....
Per cent of possible sunshine	51	49 (8 stations)
Mean wind velocity, miles per hour	9	12.3 (3 stations)*

* New York, 15; Buffalo, 12.9.

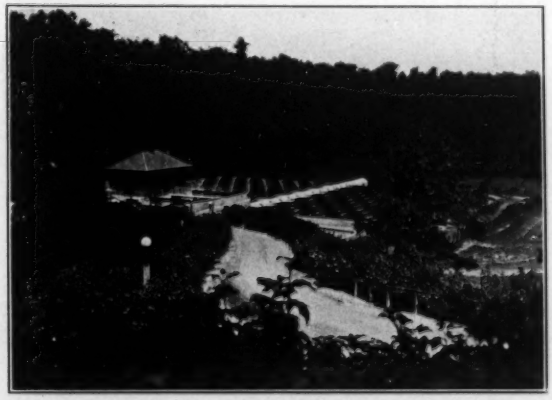


FIG. 3.—Brighton Plant—Rochester, N. Y.

One sq. ft. per capita will probably take care of Imhoff tank sludge from almost any domestic sewage in New York State. The area provided at Brighton and Charlotte (Figures 3, 4, 5 and 6) is much less than this.

Rochester has no preponderating amount of industrial wastes, difficult to treat, and so its sewage may be considered as a normal domestic sewage with the amount of sludge proportioned to the population. The record of fillings of the sludge beds is shown in Table IV.

It will be noted, from the data in Table IV, that the entire 40 beds are filled, on an average, 10 times per year.

There have been many cases where sludge 10 in. deep has dried to spadable consistency in 7 days, but it will be observed from Table IV that the average is 10 drawings in a drying season of 8 months, or a period of

TABLE IV

NUMBER OF COMPLETE FILLINGS OF SLUDGE BEDS

IRONDEQUOIT PLANT—ROCHESTER, N. Y.

	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	Mean
January														
February														
March	2			40										
April	18	20		40	24									
May	36	20	60	80	98									58.8
June	60	60	62	104	60									69.2
July	50	68	50	100	80									69.6
August	62	64	48	80	120									74.8
September	16	48	40	40	80									44.8
October	24	40	40	40	40									36.8
														354.0
November	16		20		40				Drawings on all beds, mean for 6 mos. =					8.85
December		20	20											
TOTAL	302	340	340	524	542									
40 Beds	7.05	8.5	8.5	13.1	13.55	11.8	10	9	6	10	8	10	9	9.57*
Inches, Rain	29.35	33.08	27.69	28.13	33.02	30.31	31.59	33.64	34.73	35.09	33.39	32.51	27.98	31.58†

* Mean for 10 years 1921–30 = 10.45.

† Mean for 10 years 1921–30 = 32.04.

Mean for 100 years 1830–1929 = 33.28.

about 24 days. This lengthened period is due to bad weather, to plant routine (workmen being otherwise engaged) and sometimes to sludge not being in condition to draw. The only element of the above which is aided by covering is bad weather; but with the other conditions the same, we will not find many records of complete filling of covered beds amounting to 30 times per year.

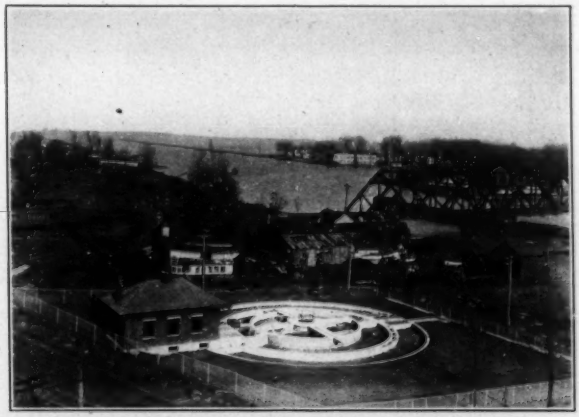


FIG. 4.—Charlotte Plant—Rochester, N. Y.

FIG. 5.—Brighton Plant—Rochester, N. Y., Sludge Beds.

With Imhoff tanks, unheated, 20 drawings in 8 months would be a fair estimate for covered beds, whereas we might have 30 drawings for a 12-month period from heated digestion tanks if the sludge could be economically handled upon removal from the beds. There would be little economy if it had to be stored and then rehandled.

The State Health Department's rules permitting the use of covered beds of one-half the area of open beds seem to be well advised.

Rochester has built several large one-story schoolhouses where cheap land was available, but where land is expensive, three-story fire-proof structures are the rule. Some such considerations may affect the type of sludge bed.

FIG. 6.—Charlotte Plant—Rochester, N. Y., Sludge Beds.

There will probably be some maintenance on a glass structure due to damage other than by the elements, for in isolated places or near railroad tracks glass offers a shining mark for missiles. Insurance, too, is expensive, the rate being $3.00 per hundred, with 50 per cent co-insurance.

Some covered beds with high concrete walls give one the impression of having been constructed with the object of sweating the sludge rather than drying it. The less wall the better, and the cheaper (Figure 7). If the expense of artificial heating is not contemplated, the best possible ventilation is required.

Various figures kindly supplied by manufacturers indicate that the cost of covers can be reduced from $0.14 to $0.20 per sq. ft. of bed if sides

and gable ends with ventilators, windows and doors are omitted. A glass roof furnishes protection from rain and snow, lets in the sunshine and provides the maximum of ventilation.

In a plant for a growing community provision should be made for liberal drying bed space for the ultimate capacity of the plant, but saving may be effected temporarily by constructing beds for the present population, then increasing the capacity by enlargement, covering, or both. This has been done at East Rochester and at Summerville, through the coöperation of the State Department of Health.

It may be timely to mention the disposal of liquid sludge without drying. If lagoons can be employed in secluded places, one of the principal

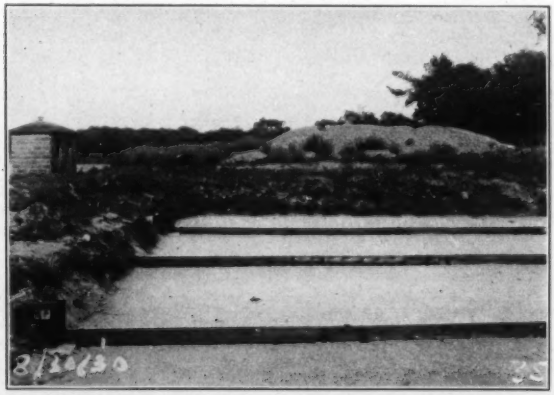


FIG. 7.—Village Plant—Albion, N. Y., Sludge Beds.

expenses of operation, the removal of sludge from beds, may be avoided. If a market is developed for wet sludge as a fertilizer by providing a tank wagon, the agriculturist may find that for a given amount of fertilizer value it will pay him to haul double the weight, for he may spray it on the ground in the winter as well as in summer.

At East Rochester there is a valve at a convenient height to discharge into a tank truck, under pressure, if desired.

Glass covers have been advocated for control of flies and odors. This may be of value at times, but well-digested sludge has no unpleasant traveling odor, and flies are not attracted to it.

It is suggested that a rule for the area of sludge beds might be formu-

lated in rational form by introducing into the formula the elements which aid or hinder drying and at the same time using a coefficient which will bring the results empirically within reason.

The following is put forth merely as a suggestion:

A = Area, sq. ft. per capita, for open beds
C = Coefficient depending on preliminary treatment (first column of figures in Table I)
R = Average annual precipitation, inches
S = Suspended solids settled from sewage, p. p. m.
N = Number of months in the drying season
T = Mean temperatures, ° F.
W = Mean wind velocity, miles per hour

For covered beds; compute A and divide by 2.

$$A = C \times \frac{R\,S}{N\,T\,W}$$

Example: Irondequoit plant, at Rochester, following two-story tank treatment.

$$A = 1 \times \frac{33.28 \times 44}{8 \times 47.5 \times 9} = 0.43$$

Mean figure for the State of New York

$$A = 1 \times \frac{38.58 \times 88}{8 \times 45.9 \times 12.3} = 0.76$$

If Shakespeare's celebrated character, Hamlet, had lived in the present time he might, with his balanced mind, have been a designing engineer, or with his care in details he would have made an excellent operator.

With appreciation of the original and apologies to the dramatist, the great Dane might have rendered his soliloquy as follows:

To glaze, or not to glaze, that is the question:
Whether 'tis better in the air, to suffer
The rain and snowfall of outrageous weather,
Or to take means against a flood of waters,
And by opposing balk them? To rest,—to think,—
No more; and by thought to say we end
The odor, and the thousand natural smells
That sludge is heir to,—'tis a consummation
Devoutly to be wish'd. To rest,—to think;—
To think! perchance to fret;—ay, there's the rub;
For in that rest from deeds what faults may rise,
When we have cast aside this daily care,
Must give us pause; there's the respect,
That makes the daily grind so interesting;
For who would bear the quips and sneers of men,
The taxpayers wail, our friends' disgusted shrug,
Unrecognized worth, the law's delay,
The insolence of office, and the spurns
That patient merit of the unworthy takes,
When he himself might rest in peace of mind

With roofs of glass? Who would such burdens bear,
To grunt and sweat under weary life;—
But that the dread of something untoward,
The chance of thunder, lightning, storms of hail,
Insurance cost, that oft puzzles the will;
And makes us rather bear those ills we have,
Than fly to others that we know not of?
Thus balanced schemes make cowards of us all!
And thus the brilliancy of our designing
Is rendered dull by difficulties dour;
With enterprises of great pith and moment,
In this respect, inertia has its way,
And projects die a-borning.

Operation of Sewage Treatment Works in Pennsylvania

Imhoff Tanks at Philadelphia*

By Thomas F. Nevin**

The experience of the writer goes back to the days when the two-story tank was known as the Emscher tank. In 1909 at the Spring Garden Testing Station, Philadelphia, an experimental Emscher tank was constructed, 5 ft. in diameter by 6 ft. deep. About February 1, 1910, this was replaced by another tank of the same diameter, 10 ft. deep. A concrete bottom forming an inverted cone, whose sides made an angle of 30 degrees with the horizontal, was placed in the wooden tank. Four feet above the bottom a galvanized iron baffle was fastened to the sides of the tank, and upon this rested an inverted funnel with its ventilating stem, concentric with which was a circular baffle, supported by the inverted funnel and extending above and below the surface of the sewage.

Crude sewage was added over a circular weir concentric with the funnel, passing down between the ventilating stem and the baffle, turning under it and flowing upward to the effluent weir around the sides of the tank. Scum boards prevented the escape over this weir of floating solid matter.

The sewage treated at the testing station was quite stale, and was heavily charged with trade wastes.

As a result of the work at the testing station, the writer learned the importance of proper baffling and of scum boards.

Sludge from the Emscher tanks appeared to be less odorous than that from the other tanks. The sludge appeared to flow more easily and dried within a relatively short time when deposited on the sand drying beds.

In 1912 the writer was appointed operator at the Pennypack Creek Sewage Treatment Works in Philadelphia. These works comprised a grit chamber, two Imhoff tanks, sludge drying beds, one acre of trickling filters, a chlorinating house and a secondary settling basin.

The Imhoff tanks were of the radial-flow type and operated in parallel. They were 30 ft. in diameter, 30 ft. in depth and designed for a total sewage flow of 2 million gallons per day, with a detention period of 2 hours. Sludge removal was accomplished by the hydrostatic head of the tank.

The sewage treated at these works was largely institutional, and con-

* *Presented at the Fourth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 26, 1930.*

** *Superintendent, Northeast Sewage Treatment Works, Philadelphia.*

tained much fat and grease. This resulted in a greasy scum over the settling compartment of the tanks, which was offensive to sight and which, if allowed to accumulate in the warm weather, gave off a rancid fat odor and attracted flies. To relieve this undesirable condition, the scum was removed by skimming nets, carted away and buried. This method of disposal required a considerable expenditure for labor.

It was discovered that the scum could be beaten down by means of a spray from a water hose. This method of scum removal was adopted. However, in a short time it was found that the digestion of the sludge was seriously impaired, and laboratory analyses indicated the sludge to be acid.

Lime was employed to neutralize the acidity of the sludge. The lime was slaked in water and piped down into the digesting sludge. The desired results were quickly realized. The sludge was restored to alkalinity and when withdrawn on the sand drying beds was found to be well digested, inodorous and easily dried. Twelve pounds of lime per million gallons of sewage treated was sufficient to maintain alkalinity in the sludge.

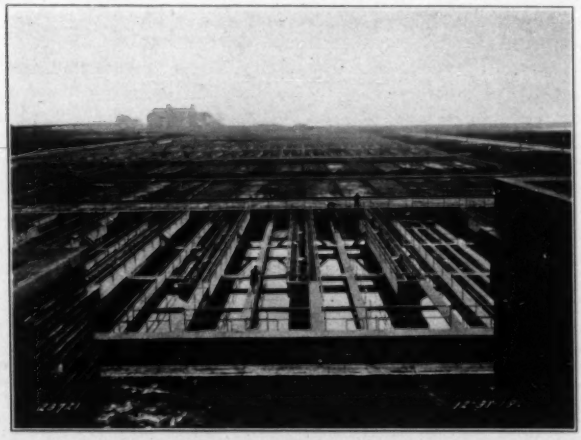
In the early stages of operation considerable trouble was encountered due to the presence of large quantities of rags which reached the sewer from the penal institutions. These rags clogged the sewage pumps at the pumping station, and at times made sludge withdrawal from the Imhoff tanks difficult. The installation of a $^{3}/_{4}$-in. clear opening bar screen materially reduced the quantity of rags deposited in the Imhoff tanks.

Where the combined sewer system is employed, inadequate or improperly operated grit chambers may also be the cause of considerable difficulty in the operation of Imhoff tanks, particularly in undeveloped sections where the wash from the road is heavy. Sufficient grit may be deposited in the tanks during times of storm to interfere greatly with sludge digestion. The removal of this heavy material from the sludge digestion compartment of the tank is quite difficult, and it is often found necessary to extend air and water hose down into the bottom of the sludge pipe to effect the removal of this material. Where the construction will permit, this grit may be removed by buckets through the gas vents.

In each of the Pennypack tanks a $1^{1}/_{2}$-in. pipe connected to the water main extends through the wall of the tank and then down along the inside face and terminates in two concentric rings in the sloping bottom of the tank. One-eighth inch perforations on 24-in. centers were drilled into the lower side of the concentric rings. It is believed a daily application of rinsing water for a 5-minute period tends to prevent the adhesion of solid matter to the concrete slope, discourages the tendency of the digested sludge to compact and lose its fluidity, and facilitates the withdrawal of sludge from the tanks. It is further believed that the use of

rinsing water aids in driving from the sludge entrained gases which have a tendency to float the mass of sludge to the top of the tanks. In spite of acid sludge in the early days of operation and, at times, of other difficulties, no evidence of foaming at the gas vents was experienced in these tanks.

In 1923 the writer was assigned to superintend the operation of the Northeast Sewage Works in Philadelphia. The present installation at the Northeast Works consists of 32 Imhoff tanks and 80 sludge drying beds, located along Wheatsheaf Lane near the Delaware River. The



Northeast Sewage Treatment Works, Philadelphia.

plant has been designed for a sewage flow of 60 million gallons a day. A Venturi meter has been provided for measuring the sewage flow.

The Imhoff tanks are built of concrete, in 4 batteries of 8 tanks each, each tank being 40 ft. wide by 80 ft. long, and 27 ft. deep below the water line. The bottom of these tanks is formed into six sludge hoppers. Two gas vents with openings 2 ft. wide by 51 ft. long are provided in each tank. Rinsing water pipes extend down into the sludge compartments for use in driving off entrained gases. Channels have been provided to permit the reversing of the direction of sewage flow through the tanks, in order to provide better distribution of the settled solid matter in the sludge digestion compartments.

The digested sludge is removed by air lifts and conveyed through

troughs to the drying beds. The drying beds are built in 4 batteries of 20 beds each, each bed being 18 ft. wide by 80 ft. long. The total depth of the filter media is about 12 inches, and consists of 10 inches of graded gravel, from coarse to fine, topped with 2 inches of sand. These beds are underdrained, and the effluent is carried to the influent sewer leading to the Imhoff tanks.

The present volume of sewage treated at these works is about 40 million gallons daily. The sewage is probably 6 to 8 hours old when it reaches the works. It contains considerable trade wastes and much oil and grease.

Seasonal, daily and even hourly variations in the character of sewage are noted. Varying results in the operation of the several tanks are observed in a given plant, and where multiple digestion compartments are provided in a single tank, different reactions may be found in each compartment.

The writer found in these tanks his first operating experience with foaming at the gas vents. Foaming occurs in the warmer weather in varying intensities, and not always in direct proportion to the degree of acidity or alkalinity as determined by the pH content of the supernatant liquor above the digesting sludge. For the control of excessive foaming, the following methods have been tried:

Application of hydrated lime in the gas vents.
Paddling with hose.
Spraying with water.
Application of rinsing water in the bottom of the sludge compartment.
Application of compressed air in the bottom of the sludge compartment.
Mixing with well-digested sludge, and resting the tanks.

Each method appears to have some merit in reducing the period of foaming and preventing the escape of the foam from the gas vents, but because of the magnitude of the plant with its 32 tanks of 6 sludge hoppers each, the application of water from a $^3/_4$-in. nozzle appears to be the most practical and effective way of controlling the foaming at these works. In spite of foaming, sludge withdrawn from the tanks has at all times been of good quality.

From my experience, I am convinced that the satisfactory operation of Imhoff tanks requires intelligent and conscientious effort founded on an understanding of the tanks and the principles involved. The operator should take every advantage of laboratory aid whenever available. Reports of analyses and tests should be reported to others. The importance of keeping a diary of work done and observations made cannot be overestimated. He should see to it that the structures and grounds present a well-kept appearance, and that cleanliness and neatness are maintained at all times throughout the entire plant.

The operator in charge of a few tanks has some advantage over the operator of a larger works, in that it is possible for him to know more intimately the characteristics of a few units than is the case in a plant involving many units.

Operation of New Castle Sewage Plant*

BY FRANK J. NUGENT**

The New Castle sewage plant has been in operation since 1927. The plant consists of coarse bar screens with 1-in. free clearance, six Imhoff tanks, each 24 ft. by 74 ft. by 27 ft. 4 in. water depth, designed and constructed for gas collection, and 24 open sludge drying beds each 20 ft. by 100 ft. in plan. The plant was designed for receiving the sewage from a future population of 60,000, which compares with the 1930 population of approximately 50,000. During flood flows, generally in the late winter, the plant is bypassed to save for the present the installation of pumping equipment to pump the settled sewage into the stream. During 1929, the plant was bypassed a total of 44 days.

The sewage flows varied in 1930 from 2.8 m. g. d. to 8.0 m. g. d. with an average of 4.84 m. g. d. The sewerage system is of the separate type and receives little objectionable industrial wastes. The raw sewage, as judged from daily Imhoff cone tests of catch samples, with 2-hour settling, has averaged 8.25 cc. per liter, whereas the effluent has averaged 0.3 cc. per liter. These figures indicate an average settling efficiency of 96.3 per cent.

Certain difficulties, principally the accumulation of undigested sludge during the winter months following the start of operation of the plant, clogging of the gas racks and, later, excessive liming, were encountered during the early period of operation of the plant. Correction of these features has resulted in normal operation and the only difficulties since experienced are the accumulation of excessive amounts of scum under the sloping walls of the settling compartment and in the gas vents in the spring of the year, which has interfered to some extent with settling efficiency. Some foaming of Tanks 4, 5 and 6 occurred later in the summer. Recent experience would indicate that the installation of a portable Wood-Trash pump for lowering the flow line of the tanks and breaking up the scum will materially reduce this one difficulty.

Raising the pH value of the sludge to between 7.0 and 7.4 has not eliminated foaming. What effect the increased pH values have had in reducing the intensity or period of foaming, is problematical. Last year the tanks were carefully limed in March so as to give a sludge and super-

* *Presented at the Fourth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 26, 1930.*

** *Superintendent.*

natant pH of 7.0 and quantities of lime were added as needed to keep approximately this pH until late fall. The pH of Tank 6, the worst foamer, varied during the summer from 6.9 to 7.4, being generally maintained at 7.1. A total of a ton of lime was added last year to this tank. Sludge withdrawn from Tank 6 has generally been of excellent quality, containing probably not over 6.5 per cent solids, and it is believed that the reason for the foaming of the tank is due principally to the character of the settleable suspended material, being finer and of a different character than that received by the other tanks, and to the higher moisture content of the sludge, with resultant less ripe sludge being present for seeding.

The 1929 sludge withdrawal data show that 27,500 cubic feet were

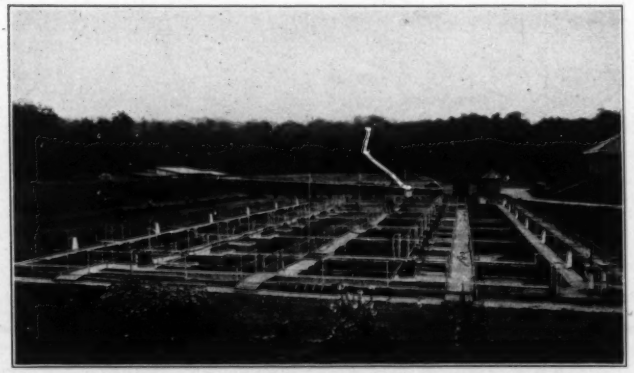


FIG. 1.—Sewage Treatment Works, New Castle, Pennsylvania. Imhoff Tanks Equipped for Gas Collection.

withdrawn from Tank 6; 26,500 cubic feet from 4 and 5; 23,000 cubic feet from 3; and 20,850 cubic feet from 1 and 2. It was particularly noticeable last year, and not so much this year, that the first sludge drawing of the year from Tank 1, which is next to the screen chamber, was not as fine in character or as granular as that drawn from the other tanks, particularly 5 and 6. From a few analyses made of composite samples of sludge withdrawn from the individual tanks there is little difference in the ash content of the sludges.

It is of interest to mention, in connection with foaming, that with provision for collecting gas, as at the New Castle plant, the gas bells tend to prevent this material from leaving the gas chimneys. However, it may foul the gas line where it connects to the bell or during the worst period,

fine material may come up through the slot, part of which passes out with the effluent. If a gas bell is removed during the foaming of one of the tanks, a thin sludge is thrown out for a short time, as though the tank were under considerable pressure. Although Tanks 4 and 5, and particularly 6, have foamed in varying degrees during the past summers it should be said that this has not been particularly objectionable in the operation and, furthermore, it is believed that foaming troubles are becoming less each year.

The usual routine in the operation of the settling compartments of the tanks consists of skimming off and burying the floating material, such as grease, soap curd, mineral oil and match sticks. Floating material other

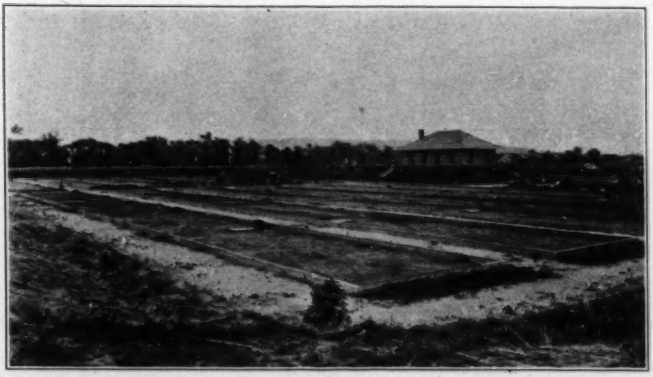


FIG. 2.—Sewage Treatment Works, New Castle, Pennsylvania. Sludge Drying Beds and Control House.

than that indicated, if there is not a lot of grease or oil present, is broken up and hosed down with the tank out of service. Generally the tanks are gone over twice weekly, or more frequently if necessary, and at the same time all of the concrete is hosed down to present a clean appearance. A good many visitors inspect the plant during the summer and a special effort is made to keep the surface of the settling compartments free of unsightly or offensive material. The slots are gone over with squeegees as needed, usually once a week, to see that they are clean.

The Imhoff tanks are designed to permit reversal of flow and it is the practice to reverse the flow weekly. Each tank has three hoppers with large openings in the cross walls to assist in equalizing the sludge level in the tanks. Regular measurements of the sludge line are taken by

means of either a pitcher pump and hose or a weighed wide-mouthed bottle with self-closing stopper. The usual experience is that there is little variation in the sludge level of the three hoppers of each tank and generally a distinct sludge line is encountered.

As the sewage temperature rises in the spring of the year, the sludge expands, due to increased biological activity. This is particularly noticeable as the sewage temperature rises from 56° to 62° F. and is accompanied by a uniform rise of about two feet in the sludge line of each tank. Immediately following this there was a marked increase in gas produced as illustrated by the gas produced increasing from a weekly average of 27,800 to 42,400 cubic feet per day within a three weeks' period, beginning with the week ending May 3, 1930. The actual gas collected in the period mentioned increased from 18,000 to 42,400 cubic feet per average day of the week, and had all the gas bells been on, the amount produced would have been as indicated, assuming the total yield would have been proportional to the per cent of gas bells on as against the total of 36 gas bells.

One other feature, probably equally as important as the temperature increase, is the raising of the pH of the sludge to an average value of 6.9+ by liming during the period mentioned. About two tons of lime were added. This undoubtedly contributed to acceleration of the rate of digestion of the sewage solids as evidenced by the marked gas increase. The fact that the sewage temperature dropped the following week to 60° F. with approximately the same gas production, and the fact that experience at other plants, where sewage and sludge temperatures are obtained, shows a delay in the increase of the sludge temperature in the spring when the sewage temperature is rising, emphasize further the relative importance of the increased pH value in accelerating the rate of digestion.

During the year 1930 a total of 145,000 cubic feet of sludge was withdrawn from the tanks to the drying beds between April and November. With the exception of the first few beds of sludge, it was all well-digested material which dried readily without odors. The usual practice in withdrawing sludge is to draw 8 inches, or 1500 cubic feet of wet sludge, onto a drying bed from each tank. A third of the 1500 cubic feet is withdrawn from each hopper so as to equalize the withdrawal, thereby not removing too much of the ripe sludge from any hopper at one time. An attempt is made to keep as much ripe sludge in the tanks as is possible at the end of the drying season for seeding the accumulated incoming fresh solids during winter operation. About $8^1/_2$ feet of sludge remained in each tank. In view of the quality of the sludge withdrawn to the drying beds in 1930, this amount was ample for the purpose. We consider all sludge drawn to the drying beds is well digested if the organic content is 50 per cent or less, if the sludge has a good color, is granular and has a distinctly tarry odor.

The weekly routine tests consist of sampling sludge at different depths in all hoppers of the various tanks, for pH and ash determination, as well as determining the sludge level.

The reaction of the sludge is adjusted by applying a lime solution into the digestion compartments. This is done by mixing 50 lb. of lime in a barrel of water and feeding the milk of lime through a funnel which is connected onto the end of a 2-in. pipe long enough to extend through the slot. This pipe is moved along the tank so as to apply the lime throughout the entire digestion compartment of the tank. The lime doses vary from 50 to 200 lb. per hopper. Depth samples, taken a week after the tanks have been limed, indicate that this method is effective in changing the sludge reaction. Without lime in the early spring, the pH will drop to 6.6 and possibly lower, if permitted. It is aimed to keep the pH of

TEMPERATURES AND GAS DATA—NEW CASTLE

Week Ending	Average of Week: Sewage Temperature	Gas Collected Daily, Cu. Ft.	Probable Gas Produced Daily, Cu. Ft.	Mean Monthly Air Temp.	Plant Bypassed, Hours	Pounds Lime Added
1929						
June 8	62	14,700	26,200	June	0	0
15	64.5	18,500	23,300	66.0	0	0
22	65.2	21,100	28,300		0	0
29	66.1	22,000	34,200		0	300
July 6	67.0	20,700	33,100	July	0	0
13	67.0	25,900	33,300	71.5	23	1800
20	68.8	31,800	35,300		0	1800
27	70.0	35,400	39,800		0	0
Aug. 3	70.0	32,700	38,000	August	0	2500
10	70.0	25,700	32,900	65.6	0	0
17	70.0	22,400	30,300		0	0
24	70.0	24,800	35,700		0	0
31	70.0	22,400	31,900		0	1300
Sept. 7	71.5	25,000	38,200	September	0	0
14	72.0	22,200	34,300	64.6	0	0
21	68.8	23,700	37,200		0	0
28	68.0	22,500	40,000		0	0
Oct. 5	67.2	22,500	35,600	October	0	3600
12	66.2	21,500	33,400	49.7	0	0
19	66.1	18,600	25,900		0	0
26	63.7	17,800	22,700		0	0
Nov. 2	62.2	25,000	25,000	November	0	0
9	62.0	24,900	24,900	39.4	0	0
16	60.3	24,100	24,100		0	0
23	58.2	16,800	16,800		98	0
30	54.8	15,300	15,300		0	0
Dec. 7	52.8	21,000	21,000	December	0	0
14	52.0	20,400	20,400	30.4	45	0
21	50.5	18,200	18,200		145	0
28	50.0	17,400	17,400		0	0

Week Ending		Sewage Temperature	Average of Week Gas Collected Daily, Cu. Ft.	Probable Gas Produced Daily, Cu. Ft.	Mean Monthly Air Temp.	Plant Bypassed, Hours	Pounds Lime Added
1930							
Jan.	4	50.0	18,000	18,000	January	77	0
	11	50.0	15,100	15,100	26.9	120	0
	18	50.0	13,900	13,900		164	0
	25	49.0	11,400	11,400		0	0
Feb.	1	49.0	16,600	16,600	February	0	0
	8	49.0	15,800	15,800	35.1	0	0
	15	49.0	17,200	17,200		0	0
	22	49.2	17,100	17,100		0	1200
Mar.	1	50.0	17,000	17,600	March	200	0
	8	50.0	16,100	16,100	35.0	67	0
	15	50.0	13,400	16,400		93	0
	22	50.0	14,800	19,200		0	750
	29	50.0	14,400	17,300		0	450
Apr.	5	50.0	15,800	18,900	April	0	300
	12	52.0	16,000	19,700	48.5	44	0
	19	54.0	18,600	23,700		0	1050
	26	56.0	17,500	24,500		0	0
May	3	56.8	18,000	27,500	May	0	0
	10	59.4	21,700	33,800		0	1050
	17	62.0	35,000	39,800		0	1950
	24	62.0	42,400	42,400		0	1200
	31	60.0	41,600	42,600		0	900

the sludge between 6.9 and 7.0 for the six warm months. The total lime used during the past year amounted to 10 tons, which is equivalent to 12.7 lb. per million gallons of sewage treated.

The above tabulation may be of interest to show the relationship of the sewage temperature to gas collected or to total probable gas produced.

The total gas collected during the year ending May 31, 1930, amounted to 7,728,000 cubic feet. For various reasons a number of gas bells were off at different times and had all the gas bells been on, the probable amount of gas produced would have been 9,500,000 cubic feet. These two figures amount to an average of 0.42 and 0.52 cubic foot of gas per capita per day, respectively. The average daily minimum gas collected for a period of a week amounted to 11,400 cubic feet, whereas the maximum amounted to 42,400 cubic feet. The minimum quantity of gas was collected during the week of January 25, 1930. Liming, withdrawal of sludge and by-passing of the plant for any period of time during flood flows in cold weather have an effect on the amount of gas produced. Once a week a CO_2 determination is made of the gas. The results of the past year show a maximum of 22 per cent and a minimum of 13.5 per cent, with an average content of about 17 per cent.

The gas is used at the plant for heating during the winter months and is used the year round under a water heater and also for laboratory purposes. Only a small per cent of the gas collected is used in these ways, the balance being burned at the plant site as a means of odor prevention.

The sewage plant is under the New Castle Department of Property and Supplies, and acknowledgment is due Mr. L. G. Genkinger, Councilman in charge, for his coöperation and interest in the operation of the plant.

Separate Sludge Digestion at Sharon*

BY S. M. FISHER**

The city of Sharon, Pennsylvania, with a population of about 27,500, operates a sewage treatment plant consisting of coarse bar screens, grit chamber, three settling tanks equipped with Link-Belt sludge-removal mechanism, six covered sludge-digestion tanks and two glass-covered drying beds. The plant has been in operation since 1928.

The system of sewers in the city is of the separate type for the most part; however, the older portion of the city is served with combined sewers. Approximately 20 per cent of the population is tributary to the combined sewers and the sewage from this part of the system is pumped to the plant, excepting during periods of high river stages.

The sewage flows received at the plant during 1929 have varied from 0.42 m. g. d. to 2.52 m. g. d., the average being 0.95 m. g. d. Results show the raw screened sewage to contain 227 p. p. m. of suspended solids.

Generally, the fresh sludge is removed from the settling tanks once each day but in hot summer months the rule is to remove it twice a day. The sludge-removal mechanism is operated for three-fourths of an hour, then the tanks rested an hour, following which the deposited solids are pumped by ejectors to the digestion tanks and the removal mechanism again operated for one hour. During the warm weather the fresh sludge is pumped from the settling tanks until a fairly thin material is obtained, whereas during the colder months the withdrawal is limited to the heavier sludge, thereby conserving heat. Eight hundred cubic feet of fresh sludge per day, or a total of 292,000 cubic feet for the past year, have been pumped to the digestion tanks. The sludge is measured by counting the ejector discharges and a factor of 0.9 is applied to represent the approximate quantities withdrawn.

Composite samples of fresh sludge are obtained once or twice a week

* *Presented at the Fourth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 26, 1930.*

** *Operator.*

and the results show the solids to vary from 1.15 per cent in the summer to 7.1 per cent in the winter. Samples of fresh sludge taken during dry weather periods or following cleaning of the grit chamber in wet weather show the ash content to vary from 22.6 to 38.7 per cent. Probably a 30 per cent ash content would represent an average of these conditions. The pH of the fresh sludge is invariably about 6.1. Imhoff cone tests of 67 samples of raw and settled sewage, the samples being six-hour daily composites, show the raw sewage to contain an average of 5.25 cc. of two-hour settleable solids, whereas the effluent samples show a removal of 99 per cent plus.

Six digestion tanks are provided which have a combined capacity of 60,000 cubic feet. The tanks are 34 ft. by 14 ft. in plan and are 22 ft. deep

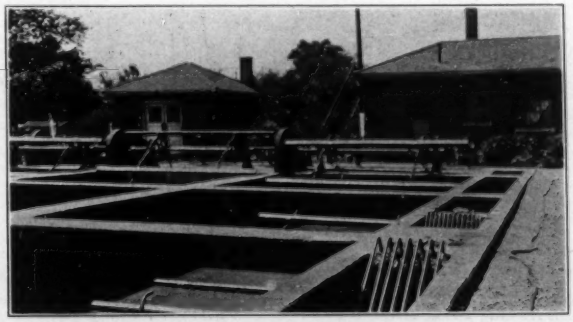


FIG. 1.—Settling Tanks, Sharon (Pa.) Sewage Treatment Works.

to the spring line of the hoppers, which are 4 ft. deep. A cross wall, with openings totaling 17 square feet, extends 10 ft. above the spring line of the hoppers and partially divides each tank into two sections, which are designated as the North and South sides. Each side is provided with a hopper bottom and a sludge withdrawal line whereas there is but one fresh sludge and supernatant line for each tank. The supernatant withdrawal line can be raised or lowered to about the middle half of the south side of the tank. Fresh sludge is admitted to each tank at one corner of the north side and the line terminates about three feet below the normal scum line.

The tanks have a small inspection well to permit observing or sampling the fresh sludge admitted or ripe sludge circulated. Lime can be applied at this point during either operation if necessary.

Provision has been made to heat four of the six tanks. The heating

system consists of a Bryant gas water heater, 2-in. coils near the bottoms of the tanks, a 17 gal.-per-min. feed-water pump and a hot water and a gas meter. The heater is controlled by an aquastat. The natural gas for the heater is procured from the local gas company.

The basis of operation of the digestion tanks is to dose one tank a day with the fresh sludge removed from the settling tanks. During the past year, with the exception of about 60 days during warm weather, only the four heated tanks have been used. The day before a tank receives fresh sludge either supernatant liquid or ripe sludge is withdrawn to make room for the incoming fresh solids. Immediately following the introduction of fresh sludge about 100 cubic feet of ripe sludge is withdrawn from the south hopper of the same tank and is reintroduced through the fresh

FIG. 2.—Landscaping of Grounds, Sharon (Pa.) Sewage Treatment Works.

sludge line. Circulation of the sludge on this basis tends to concentrate the solids and bring about a uniform sludge throughout the tank.

Table I, from results of samples collected at foot depths by means of sample bottles with self-closing stoppers, illustrates the character and uniformity of the material in the tanks.

The supernatant liquid withdrawn from the tanks generally contains about 0.35 per cent total solids and is a fairly clear liquid. Sixteen representative samples of supernatant withdrawn from the four heated tanks gave the results shown in Table II.

Ripe sludge is not withdrawn from the digestion tanks until the sludge line of the tanks approaches within 13 feet of the top of the tanks. This permits keeping a good ratio of ripe sludge to fresh solids added. About 800 cubic feet of ripe sludge is withdrawn from one tank to the drying beds, which represents a dose on the drying beds of about 10 inches.

Because of the fact that there is little difference in the ash content of the sludge in the north and south sides of the digestion tanks and since the south side sludge is invariably of lower moisture content and is more granular than the sludge on the north side, the ripe sludge is always withdrawn from the south side hopper. The sludge withdrawn during the past year has had a moisture content varying from 86.0 to 89.1 per cent. The ash content of the ripe sludge has been almost without exception

TABLE I
TANK NO. 3

Depth below Top of Tank in Feet	pH	North Side, Per Cent Solids	Per Cent Ash	pH	South Side, Per Cent Solids	Per cent Ash
10	7.1	0.38	56.8	..	...	..
11	7.1	8.35	61.1	6.7	0.37	58.8
12	7.1	8.0	60.9	6.7	0.47	55.6
13	7.1	8.3	61.0	7.0	6.0	60.1
14	7.05	8.3	61.4	7.0	11.0	63.4
15	7.1	8.2	63.3	7.0	11.0	62.7
16	7.1	8.4	60.4	7.0	10.2	62.5
17	7.05	8.2	61.4	6.95	10.9	62.4
18	7.0	8.8	62.4	7.1	...	62.0
19	..	9.1	63.0	7.05	10.7	61.3
20	..	11.6	63.4	7.05	11.9	62.7
21	..	9.8	62.2	7.1	10.0	62.3
22	..	12.1	64.5	7.1	12.5	61.8

around 65 per cent. In addition to the sludge withdrawn, a considerable quantity of sludge has accumulated in the tanks due to transfer of ripe sludge from the heated to unheated tanks or through carrying a higher sludge line in the four heated tanks.

The temperature of the sludge in the four heated digestion tanks has

TABLE II

	pH	P. p. m. Solids, Total	Suspended	Per Cent Ash, Total	Suspended
Average	7.15	3162	715	62.1	45.7
Maximum	7.2	3366	942	66.9	60.1
Minimum	7.0	2933	446	45.8	37.2

been maintained between 63° and 70° F. during the past year. The heating plant is not operated during the five summer months. A small quantity of lime has been added to the tanks at infrequent intervals. The pH of the sludge without liming drops to 6.8.

Twice a week temperature of the sludge in the tanks is obtained by means of a recording thermometer, the sludge level is ascertained by bottles with self-closing stoppers, and pH determinations of sludge and supernatant are made. All of the sludge withdrawn to the drying beds

has been well-digested material and no difficulty has been experienced in the operation of the digestion tanks.

The Sharon plant is under the supervision of City Engineer L. E. Burnside.

Note: Data in Tables I and II were supplied by District Engineer Young of the State Health Department.

Operation of Butler Separate-Digestion Tanks*

BY PAUL J. SCHAFFNER**

About two years ago the City of Butler, Pennsylvania, placed in operation a sewage plant of the primary treatment type which serves the City of Butler and that part of Butler Township adjacent to the city limits. The present population served by the plant is estimated at 30,000. The sewer system is of the so-called separate type and, excepting two small low-level lift stations, the flow to the plant is by gravity. The main interceptor of 30-in. terra cotta and cast-iron pipe is about two miles long and in order to deliver the sewage by gravity to the plant site it was laid on a low gradient.

The plant consists of a screen chamber with mechanically cleaned coarse bar screens spaced so as to provide 1-in. openings, two Dorr clarifiers 50 feet square with centrifugal pump for removing the fresh sludge, two rectangular heated sludge-digestion tanks having a combined capacity of about 75,000 cubic feet and three glass-covered sludge drying beds, each 24 by 180 feet, giving a total of about 12,750 square feet of effective drying area.

The sewage flows received at the plant fluctuate to a considerable degree with the weather conditions. The daily sewage flows, as estimated from infrequent readings taken at the effluent weir, have varied from slightly more than a million gallons following extreme dry weather to probably four million gallons after prolonged rains. Undoubtedly the reason for the increased wet weather flows is trench drains around cellar walls, which join the house connections, and old sewers with bad joints in the low sections of the city. Imhoff cone tests of catch samples secured during the day, generally at a regular time, show the raw sewage to contain an average during the past six months of 8.2 cc. of two-hour settleable solids. The comminuted character of the suspended solids in the sewage, together with the type of screen cleaner, which considerably dewaters the screenings, accounts for the fact that only about two cubic feet of

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** *Superintendent.*

screenings are collected daily. Little objectionable organic matter is contained in the screenings.

Considerable difficulty has been encountered since the plant has been placed in service in securing satisfactory and complete removal of the settled solids in the two clarifiers. At times there have been three feet or more of fresh sludge in the tanks and during warm weather this results in a septic effluent with a pronounced odor. Installing higher scraper blades appeared at first to correct the difficulty and, later, partially sealing the bottoms of the tanks near the cones to prevent possible inflow of ground water resulted in a decided temporary improvement. The accumulation of material in the clarifier bottoms comes and goes without apparent rhyme or reason. However, it can be said that this is not as variable now as during the first summer's operation.

The accumulation of this material on the tank bottoms has interfered with satisfactory settling efficiency, particularly if the accumulation lasts for any period of time. Imhoff cone tests of the effluent for the past six months show an average of 0.65 cc. of two-hour settleable solids, indicating an average removal of 92 per cent. During the past six months an average of 9150 cubic feet of fresh sludge has been withdrawn from the clarifiers to the sludge-digestion tanks each week, or approximately 225,000 cubic feet for the six months period. Infrequent analyses of fresh sludge show the moisture content to vary, whereas the ash content is almost without exception between 23 and 32 per cent. Fresh sludge is pumped from the clarifiers two to six times a day, dependent upon whether or not there is an accumulation in the tank. Before the fresh sludge is admitted to the digestion tanks it is first pumped to a 100-cu. ft. observation tank where it is measured, sampled and where lime can be added if desired.

The two digestion tanks, each about 115 by 16 feet wide, are partially subdivided by means of cross walls extending to within 10 feet of the tops of the tanks so as to form seven shallower tanks inside of each tank. Each of the smaller tanks is provided with a hopper bottom and has a sludge withdrawal pipe at the bottom and also an inlet pipe about two feet below the normal scum line. Each of the large tanks is provided with one supernatant withdrawal line. The withdrawal line is located near the center of the large tanks and consists of a swing pipe which can be raised or lowered to serve the upper ten feet of the tank. The tanks extend about 14 ft. above the ground surface, the excavation being used to bank the sides, thus minimizing temperature changes and heat losses. The tanks are covered and are heated by means of a gas water heater with 2-in. cast iron coils in the tanks placed about a foot above the elevation at which the hopper bottoms join the side walls of the tank. Natural gas with 1100 B. t. u. per cu. ft. is purchased locally for fifty cents per

thousand cubic feet. Under such conditions, gas collection could scarcely be justified from an economic point of view. The temperature of the sludge in the tanks during the past year has been between 67° and 70° F. The sludge has been heated only during seven of the twelve months.

No difficulty has been experienced since the beginning of operation of the digestion tanks and the sludge withdrawn has been well-digested material which has dried readily without odors. The basis of operation of the tanks is as follows, assuming the two large tanks are designed as A and B. Tank A receives the fresh sludge pumped from the clarifiers in the morning and Tank B receives the afternoon pumpings during the week. Hopper 1 of each of the large tanks receives fresh sludge the first day of the week and hopper 7 receives the sludge pumped on the last day of the week. The morning and afternoon pumpings of fresh sludge are alternated every week in Tanks A and B, so that each of the smaller units may receive a nearly uniform load. Either sludge or supernatant is withdrawn each week to make room for the incoming sludge. If supernatant is to be withdrawn, this is done the last of the week. In this way the sludge introduced during the middle of the week near the supernatant withdrawal line has no effect in increasing the suspended material in the liquid withdrawn. After sufficient well-digested sludge was obtained to seed the incoming fresh solids, the supernatant liquid improved markedly and generally is a clear liquid containing fine suspended matter which will settle fairly readily.

During the early months of operation of the sludge-digestion tanks, the fresh and incompletely digested sludge in the tanks was carefully limed to maintain a pH of between 7.0 and 7.3. With this liming and the heating of the sludge no difficulty was encountered in securing well-digested seeding material within a period of three or four months. In order to keep a high ratio of ripe sludge to fresh solids added, we have made it a policy not to withdraw ripe sludge until the sludge line approaches the top of the cross walls. This allows about nine feet for supernatant and scum. If the sludge line is maintained above this point it appears to result in the fouling of the supernatant. Weekly soundings in the tanks invariably show a distinct sludge line, indicating complete separation of the sludge and liquid. The depth of scum on the tanks appears to remain constant at about 8 to 12 inches. Every week 150 cubic feet of ripe sludge is circulated from the bottom to the top of each hopper of each tank. This means a complete turnover of the sludge in each compartment in about four and a half months.

Lime is added, if needed, at the time the sludge is circulated weekly. During the past six months a total of 700 lb. of lime has been added, which has resulted in an average pH of about 7.0. It is questionable whether lime is actually needed under our present operating conditions.

A total of 16,500 cubic feet of ripe sludge has been withdrawn in the past six months and, in addition, about 30,000 cubic feet more has accumulated in the tanks due to carrying the sludge line at about the same height as the cross walls. The sludge drawn to the drying beds has varied between 12 and 16 per cent solids, with an ash content of about 64 per cent, and has had all the appearance of well-digested material. The practice in withdrawing ripe sludge is to draw 9 inches of wet material onto a drying bed. The sludge is withdrawn equally from three hoppers, which is equivalent to a depth of about a foot in the tanks.

The routine operation of the digestion tanks consists of taking weekly temperatures of the sludge in the tanks by means of a Bristol thermometer, determining the sludge line and checking up on the pH of the supernatant and sludge. By securing samples of sludge each week at different depths, a good check of the pH uniformity is obtained.

Discussion

Mr. Ryan: Do I understand that you treat sludge in the digestion tank with no supernatant being allowed to flow over?

Mr. Shaffner: No overflow.

Mr. Ryan: Did you have any experience in raising the pH to 8 at the first stage of digestion and allowing it to settle back? Is there any difference?

Mr. Shaffner: None that I know of.

Mr. Ryan: I am wondering if there is any advantage in raising the pH to 8 and then dropping it back?

Mr. Shaffner: No.

Mr. Wickerham: Possibly I can answer that question. When the plant was first started considerable infiltration of ground water occurred at the digestion tank. The infiltrated water that was in the tank had a comparatively high pH and a high pH followed.

Sludge Drying Beds*

BY RALPH R. CLELAND**

Sludge drying beds usually have an average depth of about 12 inches and are composed of sand and gravel of various sizes. Greater depths are sometimes used, though seldom more than 18 inches. In some beds a very thin layer of sand, 1/4 to 1/2 in., is used at the top and in other cases depths of 2 to 6 inches of sand are used. Several layers of screened

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** *Instructor in Sanitary Engineering, The Pennsylvania State College, State College, Pa.*

gravel or broken stone are placed beneath the sand, the upper layer being sometimes as fine as 1/16 to 1/4 in., and the remaining layers gradually increasing in size up to perhaps 1 or 2 inches. Underdrains of vitrified pipe laid with open joints spaced from 6 to 15 feet apart are used except in cases where the soil is quite porous.

When sand analyses are desired in order to secure most efficient filtering, the standards developed by Allen Hazen in 1892 are specified. The terms "effective size" and "uniformity coefficient" define the sand with respect to its size and weight; the former meaning the size of grain such that 10 per cent by weight of the particles are smaller and 90 per cent larger than itself, and the latter designating the ratio of the size of grain which has 60 per cent of the sample finer than itself to the size which has 10 per cent finer than itself.

The specifications for sand for the beds at our plant as drawn up by Professor Walker are as follows:

"Sand for the sludge drying beds shall be clean and free from clay or loam. It shall contain no ingredients which tend to cement the grains together. The effective size shall not be less than 0.2 mm. or greater than 0.3 mm. and the uniformity coefficient shall not exceed 3.5."

At present there are 6 inches of Bald Eagle crushed rock sand on the beds with an effective size of 0.191 and a uniformity coefficient of 2.3. The effective size is slightly below specifications but the sand was the best of seven samples submitted for analysis because of cleanliness and reasonable price.

With regard to the area required for drying there is considerable variation due to such factors as connected population; character of sewage, whether separate or combined; climate, with respect to the duration of warm weather and the amount and distribution of rainfall; and lastly, the character of sludge as regards digestion and water content.

Early American practice was to allow an area of one-third square foot per capita, which proved insufficient where the sludge was not well digested. When the sludge has been well digested in deep tanks an area of 0.5 to 1.0 square foot per capita should be sufficient for sludge from separate sewage, depending upon the climate. An addition of 50% or more should be made in the case of combined sewage and as much as 100 per cent if trade wastes, containing abnormal amounts of solids, are present.

At our plant an area of 3750 sq. ft. of bed surface takes care of a population, according to the latest census, of 8000; giving an allowance of 0.47 sq. ft. per capita. Because of weather conditions at State College, the writer has found this to be inadequate.

Recent practice has favored glass covers for sludge drying beds. Those of Canton, Alliance and Marion, Ohio, and at Highland Park, Illinois,

are examples of typical construction. The purpose of covers is to increase the number of fillings during the warmer season by preventing interference with drying during wet weather and also to permit sludge to be drawn to some extent during the five colder months of the year. In addition to the above, there is a saving in area required of about 50 per cent and an opportunity for odor control.

Something might be said relative to the drawing and drying of sludge. When sludge is drawn, the bubbles of gas expand due to the release of pressure. This facilitates the drying-out process in that the escaping gases lift the solids and leave a comparatively thin liquid at the bottom. This is illustrated by experiments with glass cylinders where, inside of 24 hours, from 15 to 30 per cent of clear liquid remains at the bottom.

Weather conditions are of major importance in drying. If rain falls within 24 hours after running sludge onto a bed, it tends to liberate the gas, making the sludge more compact and less porous, so that it does not dry as rapidly as otherwise. If rain falls while the surface of the sludge is cracking, the water is absorbed as by a sponge; but if the sludge is nearly dry so that the cracks extend through the mass, the water soon drains away and the sludge dries again.

In order to hasten the drying process, treatment with alum has been tried at Plainfield, N. J., and at other plants where the sludge at times has been poorly digested. By applying a solution of alum to the sludge as it enters the beds at a rate of $1^1/_3$ lb. of alum per cu. yd. of sludge, the number of dryings per bed in seven months was increased from six to eleven. According to Mr. John R. Downes of the Plainfield plant, the crux of the whole treatment is to add the alum so late that the reaction is completed quiescently on the bed so that the floc is not broken up and the gas is not beaten out. It is then that the solids coagulate at the surface and the water runs out at the bottom. With well-digested sludge of low water content this treatment is not necessary, as is the case at Schenectady, where it was not found helpful.

Mention should be made of secondary tank sludge and its drying. At our plant it has been found impossible to dry this type of sludge without the addition of other ingredients. It is our regular procedure to pump it into the screen chamber, where it takes a regular course through the Imhoff tanks as does the raw sewage. Several years ago Mr. Umbenhauer, the operator at that time, attempted to dry it, by itself, since the Imhoff tanks were loaded to their capacity. Two beds were dosed experimentally —one containing the secondary sludge alone, and the other a 50 per cent mixture of the secondary sludge with Imhoff sludge. The mixed sludge dried in a period of several days more than the regular time allotted for Imhoff sludge. The bed containing only secondary sludge was not cleaned for months. In fact the dosage took place in September and the sludge

was not removed until December when it was in the frozen condition. It was then cut into cakes and hauled away—a process similar to ice harvesting. Obviously there was considerable loss of sand. No alum was used in connection with the experiment. The writer has discontinued the process of drying this sludge as a mixture, because of the extremely foul odors which are given off.

In dry weather, with open beds, well-digested Imhoff sludge becomes spadable in about ten days. Poorly digested sludge may require more than two weeks, even in dry weather during the summer.

Attention should be given to the sludge liquor discharged through the underdrains. It is usually clear but may be high in bacterial content. Tests at Baltimore indicate a biochemical oxygen demand almost twice that of raw sewage.

The writer wishes to acknowledge the fact that various figures given in the paper are taken from texts on the subject and credit is given to their authors.

Sludge Beds at Lebanon*

BY CLARENCE R. FOX**

The purpose of a sludge bed is to receive the digested sludge from Imhoff tanks, septic tanks, etc., and to permit it to dry for ready handling. The bed is so constructed that the solid matter is held and the water allowed to drain, the aim being to have the smallest possible amount of total solids in the effluent from the bed. Sludge beds are constructed in different ways in order to achieve this result, some having a bed of six inches of sand on porous soil, permitting drainage into streams without treatment of any kind.

The Lebanon sewage treatment plant, which forms the basis of this paper, has sludge beds constructed as follows: Each bed has a six-inch concrete base, surrounded by a concrete wall ten inches wide and eighteen inches deep. Upon this floor are laid three-inch drain tile (terra cotta) with loose joints to permit rapid drainage. The floor itself is so graded that the liquid portion of the sludge, or the filtrate, is drained through these drain tiles to a main collector which in turn carries the filtrate to a point of mixing with the effluent from the filter beds, both being treated with a solution of chlorine before entering the settling basins. The tile drains are covered with five inches of stone, ranging from two-inch at the bottom to three-fourth inch size at the top. This stone in turn is covered with an average of five inches of sand (Jersey gravel), but the

* *Presented at the Fourth Annual Conference of the Pennsylvania Sewage Works Association. State College, June 26, 1930.*

** *Superintendent, Bureau of Sewers, Lebanon, Pennsylvania.*

Jersey gravel was found to be very expensive, costing about $2.50 per ton delivered to our plant. We therefore experimented with granulated slag obtained as a by-product from the furnaces in our neighborhood. This product is obtained by running the slag from pig iron into water. The cost was one dollar per load of from five to seven tons, delivered at the plant.

After the furnace shut down, we were unable to obtain this slag, so we experimented further, using crude slag, which had been stored at the furnace for years. This had been crushed by rollers and screened through a mesh of one-twelfth to one-sixth inch size. The cost was sixty cents per ton, delivered at the plant.

The results show that the last experiment was most satisfactory, producing an effluent from the sludge beds containing less total solids than effluents from any of the other beds.

The sludge beds are now re-surfaced about every four months with the last-named material, at an average cost of $30.00—quite a difference from the first cost, which amounted to $125.00.

In draining sludge with a pH value of 6.7 from our Imhoff tanks, we use a solution of alum, in the ratio of one pound to a cubic yard of sludge. The solution is added at the rate of 0.8 gallon per minute. The alum causes quick coagulation and release of the water. This treatment has reduced the time required for drying the sludge about 33 per cent.

The average depth of the dried sludge when removed from the beds is five inches. The pH is 6.9. The beds have a surface area of 15,700 sq. ft. The average amount of sludge removed at one time totals 6541 cubic feet.

The sludge is stored at the rear of our plant after being hauled from the beds by means of a truck and dinky engine on a narrow gauge railroad. It is sold to farmers at the rate of fifty cents a load. When the sludge was given away we had trouble in disposing of it, but since we charge for the sludge the opposite condition prevails.

Downingtown Trickling Filters*

BY EDWIN B. WAGNER**

The sewerage system of Downingtown consists of some 7 miles of 8- and 10-in. terra cotta sewers, which drain into an 18-in. outfall sewer about 1.5 miles long, which parallels the Brandywine Creek, laid mostly in a gravel deposit from 1 to 3 ft. below the ground water level. The leakage into this outfall sewer was 60,000 gallons per day before a house

* *Presented at the Fourth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 26, 1930.*

** *Downingtown, Pa.*

connection was made. At the end of the outfall sewer there is a screen chamber, a collecting well and a pump pit containing two one-million gallon per day Wood-Trash pumps, directly connected to 25-hp. motors. The sewage is pumped a distance of 2900 ft. through a 10-in. cast-iron force main to an elevation 34 ft. above the collecting well, to a regulating or surge chamber, flowing thence by gravity to a circular Imhoff tank, 30 ft. in diameter. This tank has a sludge capacity of 5300 cu. ft. and a detention period of thirty minutes. From this Imhoff tank the sewage flows through the siphon chamber, trickling filter, chlorine dosing chamber, secondary settling tank and thence to the Brandywine Creek.

The population of Downingtown is 4544, of which total 4000 are connected to the sewerage system. The water consumption is about 500,000 gallons per day by a total connected population of 5000, but subtracting

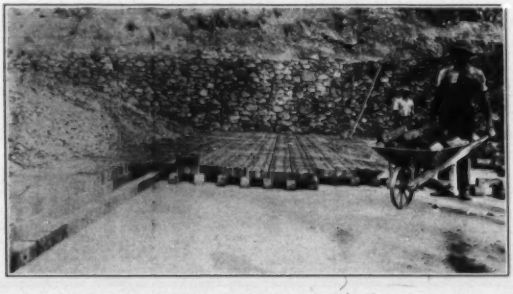

FIG. 1.—Trickling Filter Underdrains, Downingtown (Pa.) Sewage Treatment Works.

120,000 gallons used for manufacturing purposes, gives a water consumption of about 75 gallons per person per day. The average daily sewage flow is between 500,000 and 600,000 gallons, the flow varying according to the season.

The trickling filter medium consists of 1.5-to 3-in. trap-rock, 8 ft. deep, on an underdrainage system built of vitrified paving brick placed on a concrete floor. The efficiency of this filter is largely due to this underdrainage system.

The filter in plan is 87 by 126 ft. and has an area of about 0.25 acre. As designed, the filter had 61 Worcester nozzles spaced 14 ft. on centers, so located as to cover the whole bed. The filter was designed to take care of 500,000 gallons of sewage per day at the rate of 2,000,000 gallons per acre. At the rate of 600,000 gallons per day, the head in the siphon chamber remained constant and the sprinklers never shut off. This

gave poor distribution, yet with the constant flow to the bed, three drops of 1.0 per cent methylene blue indicator in a 6-oz. bottle containing filter effluent would remain blue for fourteen days.

In 1929, 36 additional nozzles were added by connecting 2-in. pipe tees to the existing sprinkler heads and laying 2-in. laterals 3.5 ft. each side of the tee. This gave a spacing of 7 by 14 ft. in all directions, these laterals being capable of being turned. These additional nozzles gave a sprinkling period of 14 minutes and a rest period of 6 minutes. Under these conditions the methylene blue color remains indefinitely.

The things of interest to a plant operator are the difficulties he meets and how he corrects them. I shall describe some of these even though the methods of correction used in Downingtown may be of little value elsewhere.

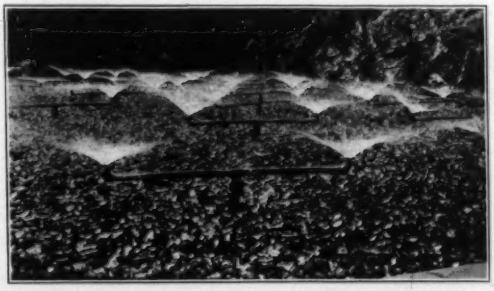

FIG. 2.—Trickling Filter Nozzles and Spray, Downingtown (Pa.) Sewage Treatment Works.

Our plant was put in operation in July, 1917, and has experienced all the ills to which a plant is subject.

Before discussing the question of operation, let us consider what we are trying to accomplish: first, oxidation; second, reduction in bacteria; third, a change in the physical form of suspended matter. At the first conference of the sewage works operators held at State College in 1926, Mr. Robert Craig stated, "A well-operated filter should show a reduction of from 75 to 80 per cent of bacteria and from 85 to 90 per cent of organic matter."

The things requiring attention on a sprinkling filter are the siphon dosing chamber, nozzles, sprinkler pipe system, underdrains and filter medium.

The greatest difficulty in operation of this plant has been the clogging

of nozzles. With a plant operating at a rate exceeding the design flow and where the flow is not constant, as the pumps work intermittently, more or less solid materials will occasionally reach the filters and plug the nozzles. Nozzles should be kept clean and free-running and the materials taken from them should be collected and carried off the bed.

Our next difficulty has been ponding or pooling. This is due largely to the suspended matter carried over to the filter but it is sometimes due to organic growths developing upon the filter medium.

This is corrected, when possible, by plugging off the nozzles and allowing the bed to dry out, but during the period that the nozzles were running constantly, other methods were tried.

Chlorine or chloride of lime, added in the siphon chamber, generally corrected pooling. Caustic soda added at the same place has been tried also, with very good results.

Trickling filters have a habit of loading and unloading, which generally is periodically—in the fall and spring. Growths are generally more prolific when the weather is warm, but filters unload more readily in warm weather and the unloading period in the fall of the year is generally shorter and not so complete as in the spring—at least, that has been our experience at Downingtown.

Sludge taken from the secondary settling tank has been equal in volume to about 40 or 50 per cent of the Imhoff sludge, when drawn weekly; but when drawn monthly is considerably less, as this sludge is very light and the least septic action brings it to the top, where it is carried off in the effluent.

Trickling filter distribution pipe systems require some attention, especially when solids are not being retained in the settling tank. The piping should be flushed, especially after having added chemicals in the siphon chamber to correct pooling.

The underdrainage system of this plant, which is flushed out once a year with a hose, has never given any trouble whatsoever.

Chemical analyses are a great help in the efficient operation of a sewage treatment plant, but an operator can generally tell more about a trickling filter from observation. The color and amount of growth on the filter medium and the growth on the collecting troughs around the filter are indicators. Green growths show good oxidation; gray growths show poor oxidation; brown or black growths, little or no oxidation.

Some plants have an abundance of worms in the filter effluent, but worms in this plant generally indicate that the bed is very heavily loaded.

Methylene blue tests are made weekly and bacterial counts made 3 or 4 times a year. This plant has given no trouble whatsoever from odors. This is attributed to the abundant water supply and the use of a fire hose, for it is our belief that cleanliness in filter operation, as in all other things, is next to godliness.

Trickling Filters at Polk State School*

BY C. F. GRACE**

The Polk State School sewage treatment plant, designed by the engineers of the Pennsylvania State Department of Health, was built in 1909, placed in operation in the spring of 1910 and has been in daily service up to the present time.

The plant consists of a screened inlet, 4 septic tanks, 16 by 80 by 10 ft. deep, dosing tank, trickling filters, chlorination house, re-settling basins and open sludge beds.

The population of the institution is approximately 3000 people. The sewage flows have varied during the past year from a minimum of 365,000 gallons to a maximum of 620,000 gallons per 24 hours, the average flow per day being around 460,000 gallons per 24 hours.

The sewage to be treated is strictly institutional and is composed of the wastes from all toilets, shower baths, laundry, kitchens, cold storage, milk rooms and drainage from stock barns. It contains a large amount of toilet and printed paper, rags and clothes, grease and soap and is lightly colored by laundry wastes. Various garments, such as towels and sheets, are salvaged from the plant daily.

The distance the sewage travels to the plant is about one mile, consequently the solids are partly broken up before entering the septic tanks. The trickling filters, of which there are two, divided by a central operating gallery, have an area, each, of 0.15 acre. The filtering medium is native broken sand stone, ranging in size from 1 to 4 inches and is placed to a depth of 6 ft., the larger stone being placed over the underdrains.

The underdrains are 6-in. half tile, laid with open joints on a concrete floor. They lead from the central operating gallery to a main collecting chamber along the side of each filter, which terminates in an 18-in. terra cotta pipe leading under the chlorine dosing house to the secondary settling basins.

The main distributing conduit is an 18-in. terra cotta pipe encased in concrete, from which 4-in. lateral distributors are taken off on 12 ft. centers. These distributors are laid on concrete piers about 2 ft. beneath the surface of the stone. Each of the laterals can be shut off, but can be flushed only by removing the end nozzle. The nozzles are the Taylor circular type with 1-in. orifices and $^3/_{16}$-in. spindles. They are screwed into 3-in. flanged risers leading from the 4-in. laterals and are spaced on 14-ft. centers, staggered in such a way as to form apexes of hexagons.

Adequate provisions have been made for flushing the underdrains of

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** *Sewage Treatment Plant Operator, Polk State School.*

the filters from the central operating gallery. The settled sewage from the septic tanks flows directly into the dosing tank, which is equipped with a single 10-in. automatic siphon. Variations in flow increase or decrease the frequency of dosing and also the size of dose, as there is a steady flow into the dosing tank during discharge.

The average number of doses per 24 hours is 70 and the average size of each dose is 6000 gallons.

The distribution over the filters is very poor due to low head. When the plant was built every inch of grade from the institution to the end of the outfall sewer at the creek had to be utilized, with the result that the siphon is operating on a low head. The maximum effective head on the nozzles is 5 ft. when the siphon "flows" while the minimum head on nozzles is 2 ft. 3 in. when the siphon "sniffs."

The dosing tank, with a flat bottom, does not give uniform distribution by means of the spray from fixed nozzles discharging under a falling head. Consequently only about 65 per cent of the filters are actually effective under present conditions.

Filtered effluent appears in the collecting gallery 2 minutes after the sprays start and the flow increases in volume for about 2 minutes, remains constant for about 2 minutes after the sprays stop, and then starts to decrease. But the filters are not drained until about 6 minutes after the sprays stop, leaving a period of 3 to 10 minutes of rest between doses.

Filter flies have not been sufficiently numerous to be objectionable. They are more noticeable in the evenings but take refuge in the evergreen trees throughout the heat of the day. Odors from filters are not noticeable at any great distance and even during a strong wind are not easily detected even by persons not accustomed to sewage plants. There is a slight septic smell to the septic tank effluent when it flows over the overflow weir but it seems to break up and disappear, as no odors are noticeable along the state highways 1000 feet away.

There has been no pooling around the sprinkling nozzles either in summer or winter, but this can be partly attributed to the method of operation. One row of nozzles is rested from 10 to 24 hours each day, which has a tendency to keep down a heavy growth or, in other words, to keep the stone in good condition and free of algae. Another result of the short rest periods is the unloading of deposits of fine solids discharged from the septic tanks. In the spring one filter is cut out of service for several days, and when placed in operation the unloading period will last from 1 to 3 weeks. The growths in the distributing laterals also loosen and can be flushed out in long pieces.

The stone in the trickling filters is relatively free from disintegration. About two wheelbarrows full of sand are removed from the secondary settling basins in the spring and very little throughout the summer months.

On two occasions when it has been necessary to dig into the filter, very little sand was found deposited among the stone. The stones were bright and clean but covered with a sticky, colorless, slimy growth and millions of angleworms were living among the stone.

The final effluent from the plant has always been of good sanitary quality, odorless, relatively clear and with little suspended solids.

I wish to express my appreciation to Charles H. Young, District Engineer, and to his associates for helpful counsel in the technical and practical work essential to the operation of the plant and to Dr. Harvey M. Watkins, Superintendent, for his interest and coöperation in repairing and modernizing the plant during the past three years.

Sewage Plant Operation by pH Control*

BY H. HEUKELEKIAN**

Organic matter of domestic sewage solids is composed of about 40 per cent fats and oils, 10 per cent cellulose and hemicellulose, and 35 per cent proteins. About 50 per cent of the fats are ultimately decomposed under favorable conditions of digestion. The true cellulose and hemicellulose decompose very readily and completely. Proteins also decompose but not very completely. Since the fats are present ordinarily in such large quantities and a high percentage ultimately decomposes, it can be readily appreciated that fats determine the rate and extent of digestion to a great measure.

Under anaerobic conditions of decomposition high concentrations of organic acids accumulate from the digestion of any of these constituents. If the same substances were decomposed aerobically no such accumulation of acids would take place but instead the substances would be completely oxidized, giving rise to carbon dioxide and ammonia, with very little if any organic acids as intermediate products.

The insoluble organic substances, such as fats, cellulose and many of the proteins, are first hydrolyzed by the action of bacterial enzymes, giving rise to a number of intermediate organic compounds, among which the fatty acids are the most important. In spite of the fact that the ionization of many of these fatty acids is low they accumulate in such quantities that they cause the pH value to drop from 6.4–6.8 to 5.2–5.0.

These fatty acids in themselves are not poisonous to the bacteria but, on the contrary, serve as a good source of food, if properly neutralized. It is now generally known that bacterial action is retarded at low pH values, so that even in the presence of an ample food supply the bacteria become relatively inactive. A pH value of 5.0, though not sufficiently low to kill most bacteria, is still sufficiently low to retard their activity materially.

Such is exactly the situation in the digestion of fresh sewage solids. Readily available organic substances are attacked immediately, giving rise to high acidity and low pH values. This acidity retards the activities of bacteria to such an extent that proper digestion of the solids will not take place in less than 200 days at a temperature of 70° F. During the long period of digestion part of the organic acids are attacked and slowly destroyed, while another portion is being gradually neutralized by alkaline substances produced from the slow decomposition of proteinaceous sub-

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** *Research Bacteriologist, Dept. of Sewage Research, New Jersey Agricultural Experiment Station.*

stances. Thus the pH value gradually rises, and as this pH value increases and comes closer to the optimum value the digestive action is accelerated.

When ripe sludge is available and fresh solids are digested in the presence of ripe sludge, bacterial action is stimulated, not only because of the presence of large numbers of desirable types of bacteria, but also because the ripe sludge is an excellent agent for regulating the pH value of the digesting mixture. When ripe sludge is present in proper proportions the pH value of the digesting mixture seldom drops below 6.8. Of the alkaline substances present in ripe sludge which might be instrumental in such a perfect regulation of the pH value, ammonia is the most obvious and important. It is usually present in ripe sludge in quantities as high as 2000 p. p. m. What other substances, if any, may play a rôle in this pH regulation by ripe sludge, we do not know. Upon the assumption that the ammonia is combined mostly as carbonates or bicarbonates, we have added these salts and di-potassium phosphate to fresh solids without ripe sludge and have obtained perfect pH regulation.[11] In the case of regulation of the pH value by lime, the quantities added have to be kept at a minimum because of the toxic action of large quantities of lime. This necessitates frequent and small applications of lime. By the addition of ammonium carbonate and ammonium bicarbonate and K_2HPO_4, however, we have been able to so regulate the pH values of fresh solids that they never go below 6.8 or 7.0, even in the absence of ripe sludge. Thus by artificially eliminating one of the factors in the function of ripe sludge, *i. e.*, pH regulation, we have been able to evaluate some of the seeding value of ripe sludge.

We have found, in short, that fresh solids without ripe sludge but with artificial buffer salts, digest better than fresh solids alone or even fresh solids treated only with lime, either initially or at frequent intervals. But the digestion of fresh solids treated in this way is not as fast as digestion of fresh solids seeded with ripe sludge, thereby indicating to us that in addition to the buffering effect, ripe sludge is also beneficial to digestion by furnishing a large number of the organisms necessary for digestion.

From a practical standpoint a single adjustment would be all that would be necessary in starting a new digestion tank with the use of these chemicals, if they could be procured cheaply, whereas with lime it is common experience to make constant additions to maintain the pH value.

In order to discuss more intelligently and clearly the research work done on pH control it will be convenient to consider the following phases of the subject: the addition of lime or other alkaline salts to fresh solids or to seeded mixtures in the laboratory under well-controlled conditions; the addition of lime when starting new digestion tanks; the addition of lime to digestion tanks in cases of overloading; the addition of lime to correct foaming.

Laboratory Experiments with pH Control

Unseeded Solids.—Laboratory experiments on the digestion of fresh solids have shown conclusively that lime very materially affects the time required for digestion. The following figures are reported by Rudolfs[15] and illustrate this observation:

	Digestion Time in Days*				
	10° C.	18° C.	24° C.	29.5° C.	35° C.
Unlimed	360	200	142	61	89
Limed	325	150	108	54	108
Per cent reduction in time of digestion due to lime	9.7	25.0	24.0	11.5	+21.0

*Minimum time necessary for sludge drawing and not for complete digestion.

It is apparent that lime brings about the maximum reduction in digestion time at temperatures between 18° and 24° C. (25 per cent). At 10° and 29.5° C. the reduction in digestion time is only about 10 per cent due to lime although at 29.5° C. the total digestion is less than at 24° C. for both unlimed and limed solids. Furthermore, at 35° C. the digestion time of limed solids is longer than for unlimed solids. It would thus appear that temperature is a more important factor than lime, but that at 18–24° C. lime brings about a 25 per cent reduction in the time of digestion. Not only are the rates of digestion and of gas production accelerated but also the yield of gas is somewhat increased by the addition of lime. In the digestion of fresh solids at 24° C., in 200 days 755 cc. of gas were produced, whereas 905 cc. were produced when the same solids were limed. Thus liming increased the total gas yield 16 per cent in addition to increasing the rate of digestion by 25 per cent. The quality of gas produced is nearly identical for limed and unlimed fresh solids. Limed solids gave a greater reduction of volatile matter and increase in ash. In order to achieve these results, however, it is necessary to make several small additions of lime. Enough lime should be added to just neutralize the acidity and to provide a little excess that will bring the pH value to 7.2–7.4. The artificial neutralization of acids with lime will provide a medium favorable for bacterial development and the neutralized salts of the organic acids will serve as a good supply of food and as a rich source of gas. If, on the other hand, the additions of lime are great and the pH value is increased beyond 8.0 the medium will become unfavorable for bacterial development, the number of bacteria will become variable and digestion will be retarded. Increasing the lime dosage still further will result in a reduction in the number of bacteria until sterile conditions are reached.

Seeded Solids.—Laboratory experiments with seeded mixtures have shown that at 70° F. with 2 per cent daily additions of domestic and strictly fresh solids, lime will not be necessary to maintain the reaction.[14] On the

other hand, if the reaction of solids added daily is kept at 7.3–7.6 the daily charges can be increased from 2 to 3.5 per cent dry solids (on the basis of ripe sludge). Thus, unadjusted but properly seeded material may require a digestion space at 70° F. of not less than 2.6–2.7 cu. ft. per capita. With reaction control this per capita digestion capacity can be reduced to 1.4–1.5 cu. ft.

Freshness of Raw Solids.—As indicated above, one of the essentials for successful operation with pH control is that the solids should be as fresh as possible. In Imhoff tanks this is automatically taken care of, while in separate sludge-digestion tanks it is essential, both from the standpoint of economy of lime and avoidance of odors and nuisances, to add the solids as fresh as possible. With the mechanical type of sedimentation tanks this can be readily accomplished, but with plain sedimentation tanks the danger lies in letting the solids accumulate too long before transferring to the digester. The greater the period of septicity, the greater the acidity produced and the greater will be the amount of lime required. With material accumulating in sedimentation tanks for prolonged periods in warm weather, liquefaction produces offensive odors and contaminates the effluent. Under such conditions it is easy to see why there would be not only no reduction in the B. O. D. and *B. coli* of the effluent over the influent, but actually an increase.

Kind of Alkaline Material.—The question has been raised as to what kind of alkaline substance is the best for pH regulation. The alkali most commonly employed, if not the only one from a practical basis of application, has been lime. However, under laboratory conditions a number of other substances have been investigated. Fair and Carlson[5] have reported the results of studies with lime, marble, dolomite, calcium carbonate, soda ash and caustic soda. Soda ash and caustic soda retarded digestion. They concluded that calcium carbonate gave the best results and recommended it for its ease of application and its self-regulating character. It is true that calcium carbonate does not have the toxic action of large amounts of lime and therefore it is possible to add the whole quantity of calcium carbonate required at once, but it required 4 times as much calcium carbonate and over 10 times as much marble or dolomite as lime. Naturally, the cost of precipitated calcium carbonate would be prohibitive while the use of dolomite or marble, even if as efficient as lime in pH regulation, would necessitate the handling of 10 times the quantity of dry material as lime, both during application and in sludge withdrawal. Rudolfs and Zeller[9] found that dolomite and calcium carbonate increased the rate of gas production slightly and lime considerably, as compared with untreated mixtures. The percentage of volatile matter reduction was greatest with lime and least with dolomite. The total quantities of methane produced from the different mixtures were the same after a prolonged period

of incubation. They also found that the quantity of dolomite needed was 20 times greater and that of calcium carbonate 8 times greater than lime.

Fischer[9] used $NaNO_3$ in a study of the effect of chemicals on the rate of digestion. He found that sodium nitrate hastened the decomposition. Sodium nitrate, though not an alkaline salt in itself, gives rise to alkalinity as a result of the denitrifying bacteria, which reduce the nitrate to nitrogen gas and leave the sodium ion free.

Mention has been made above of the use of carbonates and bicarbonates of ammonia for pH regulation. Of all these substances tested, however, lime has been universally accepted for plant applications.

pH Regulation of Digestion Tanks

With regard to the application of the results of these investigations to actual plant control, the information is necessarily more or less indefinite and contradictory. Bachmann[1] has made an excellent attempt to summarize the status of lime treatment by means of a questionnaire. Of the 30 questionnaires returned ten related to Imhoff and twenty to the separate sludge-digestion type of plants, mostly from the east and middle west of the United States. He concludes from the answers that in practically all cases the addition of lime was beneficial to digestion. In two instances the addition of lime apparently had no effect. When used in excessive amounts, a detrimental effect was noted. The range of pH values to which the tank contents were adjusted varied from 7.3 to 7.8. In some cases it was reported that it was difficult to secure pH adjustment within a narrow range, such as 7.3–7.6. This would entail in large plants the use of enormous amounts of lime and in smaller plants careful control.

Where and How to Add Lime.—The best way to apply lime was to add it to the incoming raw sludge. Milk of lime gave better distribution than hydrated lime when added to the surface. Both gave equally good results when added to the incoming raw sludge.

In Imhoff tanks the usual way of applying the lime is to add it to the scum in the gas vent and to work it down either with some implement or with a stream of water. The lime should be thoroughly mixed with the sludge. In order to accomplish satisfactory mixing, sludge is pumped from one tank into another, from one hopper into another or from one side of the tank to another. Large quantities of lime dumped in at one time, without proper mixing, might result in a very strong alkaline reaction near the bottom of the tank, with little beneficial action. Sometimes this procedure might even be detrimental. With separate sludge-digestion tanks the most common and convenient method is to add the lime to the incoming raw sludge by hand or by a lime distributor. The addition of lime to the incoming sewage for the purpose of pH regulation is a wasteful procedure, which may cause incrustation in the filter bed.

As indicated by laboratory experiments, experience in plant operation also shows that the pH value must be constantly adjusted, otherwise it drops gradually. To adjust the reaction of a tank full of sludge that has been allowed to become acid is much more difficult and costly than to keep the reaction up day by day. If the incoming solids are adjusted to pH 7.2–7.4 daily, the tank contents will not need to be adjusted, provided there is sufficient ripe sludge present. The addition of large quantities at intervals upsets the biological balance and causes a retardation of digestion.

Foaming.—Lime has been used to correct foaming in Imhoff tanks or in separate sludge digestion tanks, with varying results. Some claim foaming is reduced temporarily or permanently by pH control; others claim that it is not reduced; while still others consider that lime treatment increases foaming. In order to harmonize these contradictory views it is necessary to discuss the causes of foaming.

Foaming usually occurs under a variety of conditions. It usually occurs in an overloaded tank, where the amount of ripe sludge present is not enough to take care of the incoming solids, *e. g.*, where the tank capacity is insufficient. Solids accumulate faster than they are digested, an acid condition is created, and the percentage of CO_2 in the gases increases. Foaming also takes place in unheated tanks in the spring when the material accumulated during the winter, with little digestion, begins to digest suddenly and actively, causing a violent gas production. The addition of lime to such overloaded tanks before aggravated foaming occurs would of course stimulate digestion if the overloading is not excessive and would have the same net result as increasing the capacity of the tank to a certain extent, thus tending to prevent foaming. But once foaming is taking place, *e. g.*, solids are digesting but with an improper biological balance, the net result of the addition of lime is to aggravate foaming by causing a more active digestion until the excess load has been digested. Occasionally there are tanks which are so excessively overloaded that lime alone, which at best causes a 25% reduction in digestion time, cannot make up for the overloading. In such cases temperature control should be provided, in addition to pH control, or more tanks should be built. If these factors are borne in mind, most of the contradictory views on the effect of lime on foaming can be reconciled. In addition to its biological action, lime brings about certain physical changes in the dispersion of the colloidal matter in the mixture which may be instrumental in repressing foaming. Changes in surface tension and chemical interaction also will have to be reckoned with in the action of lime.

Let us now review some of the published reports dealing with the pH control of digestion tanks.

Rudolfs and Zeller[16] reported on the operation of two new separate sludge digestion tanks at Plainfield, N. J. These tanks were heated to 68° F.

and the pH value of the contents maintained at 7.2–7.3 by the addition of lime. Due to comparatively large quantities of partly digested material added it was necessary to use on the average 1 lb. of lime to 0.2 cu. ft. of material added.

Coburn[2] reports on the practical application of hydrogen-ion control to the digestion of sludge in an Imhoff tank at Plainfield, Massachusetts. He illustrates the troubles encountered in starting a new tank without sufficient ripe sludge and how the judicious application of lime to the digestion chamber helped the operation. At first, lime was added near the slots in the sedimentation chamber, but soon a crust of $CaCO_3$ formed in the filter bed which interfered with filtration. Lime was then sprinkled over the surface of the scum and worked down with a long shovel. The unfavorable acid condition which had been created in the tank previous to lime application and which produced small amounts of offensive sludge and a large amount of offensive scum was corrected. Coburn concluded that under favorable conditions it is practicable to control the hydrogen-ion concentration of the sludge in an Imhoff tank by the judicious application of lime to a pH value of 7.3–7.6. Once favorable digestion is established, it may not be necessary to continue application of lime.

At New Castle, Pennsylvania, Donaldson[4] reports similar experiences. The new plant was put into operation in the beginning of winter, which resulted in a large accumulation of solids. He recommends the use of lime to start new tanks when ripe sludge is not available. He found that the addition of lime to the upper part of the digestion tank was unsatisfactory but recommends, instead, the circulation of sludge during lime addition. In dosing acid tanks he considers it wasteful to undertreat. He recommends the use of hydrated lime of high magnesium content as being most economical.

During the second year of operation at New Castle,[4] considerable quantities of lime were used to prevent the tanks from becoming acid. After the first sludge drawing in June, however, no attempt was made to hold the pH higher than 6.8.

Daniels[3] in starting the new Imhoff tanks at Trenton used at first small amounts of lime to keep the contents around 6.6–6.8. He progressively increased the dosage but could not prevent foaming He finally increased the dosage of lime to 250 lbs. per million gallons, with successful results, the pH coming up to 7.0. After foaming subsided he reduced the amount of lime to 110 lbs. per million gallons. He believes that if the proper alkalinity had been established initially a saving of lime would have resulted. All through the winter, application of lime was kept up and in the second summer no foaming occurred but due to the presence of mash the dosage had to be increased to maintain a pH of 7.3. In the control tank, to which no lime was added, the digestion proceeded in a normal fashion, although

slower. Lime additions were discontinued in all the tanks and the pH dropped to 6.6. No foaming or any other undesirable effects followed. This is to be attributed to the high iron content of the sewage (800 p. p. m.) which reduces the digestion time very materially, as has been shown in our laboratory.[18]

At Antigo, Wisconsin,[7] the pH value of the sludge in the separate digestion tanks was adjusted with milk of lime from the start of operation. After 3 months a pH value of 7.4–7.6 was maintained without the addition of lime, in spite of the fact that whey from a cheese factory was introduced. The tank was heated and had a capacity of 5.0 cu. ft. per capita. This illustrates the fact that where there is sufficient capacity, no foaming troubles need be encountered even when starting and that lime will not be necessary during regular operation. Fischer[8] concludes from the separate sludge-digestion experiences in small plants in the middle west that, although adjustment with lime to pH 7.3–7.6 is beneficial, in several instances it caused foaming in a tank containing a large quantity of acid sludge which had been allowed to accumulate during cold weather. Where such conditions exist he recommends that the tanks be emptied and started anew in warm weather, adjusting the reaction at the start. This will require less lime. Addition of lime to a foaming tank affords only temporary relief, since the lime will hasten digestion and cause more gas to be liberated.

At Decatur, Illinois, Hatfield[10] reports his experiences with Imhoff tanks. The temperature of the sewage is usually high. The average temperature of the sludge digestion compartments is 32° C. in summer and 21° C. in winter months. Foaming has always followed long periods of shutdowns. The worst foaming was when the tanks were well inoculated with digested sludge. Lime treatment reduced the violence of foaming but was too costly. Foaming is not necessarily indicated by pH values below 6.6–6.8. Low alkalinities and high carbon dioxide are better indices of poor digestion and probable foaming.

Keefer and Rudolfs[12] reported the results of two years' studies on the effect of reaction control on the rate of sludge digestion conducted on a large scale at Baltimore. Daily charges of settled solids, acid in character, were added to unheated separate sludge digestion tanks. The results indicated that by raising the pH value of the solids from 5.4 to 7.3 much more material could be digested in a given period.

How Much Lime to Add.—(To a tank that is acid and probably foaming.) As has been indicated above, the most convenient and economical way of treating a tank that has become decidedly acid and is badly foaming is to empty it out and to start anew with careful control of pH value and temperature from the beginning. However, under certain circumstances it may be necessary to adjust the reaction of the contents of the entire tank. It is first necessary to have an accurate estimate of the

amount of sludge present in the tank. If there is a separation into definite liquid and sludge and scum layers it will be necessary to determine the volume of each layer and to have an average value for the dry solids concentration of each layer, and to calculate the average solids content of the whole chamber. There usually will not be a great variation in the pH value of the different layers, but if there is, an approximate average figure should be determined. From these figures it will be possible to determine from published curves[14] the grams of lime to add per cu. ft. of sludge. In case of acute foaming where the distribution of solids is uniform, all that is necessary is to determine the solids and the pH value of a sample taken sufficiently deep to insure approximately average conditions, then with the use of the chart to determine the amount of lime necessary. A more accurate method is actually to add measured amounts of lime to a series of samples of sludge until the desired pH value is obtained and from this to calculate the amount of lime necessary to adjust the entire contents of the tank.

pH Determination.—Let us discuss briefly the method used for pH determination. In order to obtain a sample for colorimetric comparison several methods have been suggested: filtration through paper, with or without suction; filtration through glass wool; and centrifuging. Filtration through paper raises the difficulty of absorption of some of the ions by the paper and the probable increase of the acidity due to the acid nature of some of the filter paper. Suction is also objectionable because it liberates CO_2 and causes a rise in the pH value. In the colorimetric method of pH determinations it is very necessary to obtain as clear a liquid as possible, otherwise the dye is adsorbed and causes a false reading of the pH value. Filtration through glass wool and centrifuging do not always yield such a clear liquid. Dilution has been suggested[6,13] and gives satisfactory results. With highly buffered materials such as sludge, diluting the material ten times does not bring about marked change in the pH value and the diluted sample still gives, after a period of sedimentation of 1 hour, a clear liquid which can be readily compared with the standards in a double tube comparator. It has also been suggested to increase the concentration of the dyes. In addition to the standard buffer solutions it is possible to use the standard colored glasses for comparison and these seem to give good results.

Summary

Laboratory experiments show that the addition of lime to unseeded solids accelerates the rate of digestion by at least 25 per cent and causes an increase of 16 per cent in the yield of gas. Several small additions of lime should be made to accomplish this result. With the use of ammonium carbonate and bicarbonate and di-potassium phosphate, the pH value of di-

gesting fresh solids has been regulated so that the pH value after the initial adjustment did not decrease below 6.8–7.0. Such a regulation with these chemicals accelerates the rate of digestion of unlimed unseeded solids but is inferior to the digestion of seeded solids, indicating the seeding value of ripe sludge. At the present time, however, lime is the only alkaline substance used for pH control on a large scale. Other substances such as calcium carbonate, dolomite, marble, etc., have been suggested from trial on laboratory scale, but from a practical standpoint their value is not accepted because large quantities of these substances would have to be used to accomplish the same results as with lime. Properly seeded digesting mixtures (2 parts of fresh to 1 part of ripe solids) do not require lime adjustments to maintain the reaction, provided the raw solids are strictly domestic and fresh. When such solids are limed, however, the daily load or charges can be increased from 2.0 per cent to 3.5 per cent. The septic solids require more lime for pH adjustment than do strictly fresh solids.

The value of lime in improving the action in the digestion tanks and especially in starting new tanks has now been generally accepted. In starting a new tank which is not provided with heating facilities, it is best to avoid the cold weather because otherwise the undigested solids accumulate in an acid condition and with the onset of warm weather rapid decomposition sets in, causing foaming. Excessive amounts of lime will be necessary to put such tanks into working condition, hence under these conditions it would be best to empty the tanks and to start anew in warm weather, with judicious applications of lime.

Lime should be properly mixed with sludge. In Imhoff tanks this is accomplished by adding lime to the sludge while pumping it from one tank to another or from one hopper to another. In separate sludge-digestion tanks, add the lime to the daily charge of raw solids.

If it should be necessary to adjust the reaction of the contents of a tank, data concerning the volume, concentration and the pH value of the sludge should be obtained first. Then the amount of lime can either be calculated from published charts or determined from laboratory tests on small quantities of sludge to which different amounts of lime are added and the pH values determined.

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Sewage Works Operation and Control*

BY C. E. KEEFER, *et al.*

This Committee was appointed in 1926 by the Executive Committee of the Sanitary Engineering Division, to deal with the underlying principles, the adoption of which seems to insure the satisfactory operation and control of sewage works. A brief progress report was made by the Committee and presented to the Division at the Annual Meeting of the Society January 19, 1928.[1] Since that time the Committee has been studying such questions as the best manner of obtaining funds to operate sewage works, the qualifications and adequate compensation of the personnel employed in such works, the establishment of schools for sewage works operators and the question of control analyses at sewage works.

The Final Report of the Committee was presented to the Executive Committee of the Sanitary Engineering Division April 9, 1929. After thorough discussion, it was adopted by the Division at its meeting in Cleveland, Ohio, July 10, 1930. In the light of this action and after further review, the report is herewith presented in its final form.

C. E. KEEFER, *Chairman*,
W. R. COPELAND,
A. L. FALES,
J. A. VOGLESON,
F. H. WARING,
Committee

June 17, 1931

The Operation and Control of Sewage Works

The art of designing and constructing sewage works has advanced to the stage where municipal sewage can be treated adequately in order to produce an effluent of any reasonable degree of purity. The operation of such works, however, has not kept pace with the advances made in their design. A survey of these works has indicated that many of them are poorly operated, with the result that the welfare and health of many communities are imperiled. The outstanding reasons for the unsatisfactory operation of sewage treatment plants are the lack of sufficient operating funds and the need of well-trained and efficient personnel. The purpose of this report is to outline the underlying principles which it seems necessary to follow to insure the satisfactory operation of sewage works.

* *Final Report of the Committee of the Sanitary Engineering Division, American Society of Civil Engineers. Presented at the meeting of the Sanitary Engineering Division, Cleveland, Ohio, July 10, 1930. Reprinted by permission of the American Society of Civil Engineers.*

[1] *Proceedings, Am. Soc. C. E.* (March, 1928), Society Affairs, p. 153.

State Supervision of Sewage Works

Each state department of health or other similar state board through adequate legal statutes should have approval of the design and control of operation of the sewage works in its own state. The state board should also have sufficient appropriations and adequate personnel to keep in touch with all sewage treatment works in the state. In case a sewage plant is not operated and maintained in a satisfactory manner the board should have the legal right to require the owner to employ a competent person or persons to operate the plant and make such repairs and improvements as may be necessary. The necessary legislation to accomplish this purpose is typified by the Ohio Law given in Appendix I. (*Editor's Note:* The appendices have not been reprinted, but may be obtained from Mr. Keefer, if desired.) Where adequate laws do not exist, legislation should be passed conferring such powers upon the state board of health.

Financing Sewage Works Operation

One of the most important matters affecting the successful operation of sewage works relates to the securing of sufficient funds for this purpose. Most sewage works owned and operated by municipalities, or other political sub-divisions, are financed out of the general tax levies. It is frequently the aim of those public officials who decide the amount of money to be appropriated for annual operating budgets to keep the tax rate as low as possible. The result is that funds for the efficient operation of sewage plants are generally inadequate. Such have been the findings from a survey made by the Committee. In order to correct such a condition attempts have been made to find some other practicable method of financing sewage works operation.

The Legislature of the State of Ohio has passed a law (see Appendix II) which permits the council of any city or village in that state to establish by ordinance equitable rates or charges for sewerage service. It is provided in the Ohio law that these rates are to be paid only by those persons who are served by the sewerage system. In Ohio a number of the smaller cities including Delaware, Oxford and Salem and the large city of Dayton have passed the necessary ordinances as a result of this law. The ordinances providing for sewer rentals for Delaware, Dayton and Oxford are given in Appendix III.

The Committee believes that as far as practicable the maintenance and operation of all sewage works as well as the tributary sewerage systems should be financed by funds collected from the persons or property owners who are benefited. These funds should be levied in the form of rents, payable at stated intervals, and should be used only for the maintenance and operation of the sewage works and the sewerage system. The financing

of the cost of construction of sewerage works should be borne by the entire communities benefited.

Qualifications for Sewage Works Superintendents

The operation of sewage works should be in the hands of competent men. The number of the personnel and their training depends upon the size and the type of the treatment plant. The responsibility for the satisfactory operation of the plant rests largely with the superintendent. For that reason he should have the necessary training and experience to qualify him properly for the responsibilities of his position.

The qualifications for superintendents of sewage works of different types and sizes have been classified, roughly, as follows:

A Grade A Superintendent should be a graduate of an engineering or technical school of recognized standing, and should have had experience for not less than five years in problems relating to sewage treatment. He should also be able to supervise and direct the work of others.

A Grade B Superintendent should be at least a high school graduate with additional training in chemistry and engineering, and should have had experience for not less than five years in problems relating to sewage treatment. He should be able to supervise and direct the work of others.

A Grade C Superintendent should have had at least an elementary school education with the training equivalent to that of a skilled mechanic or skilled laborer. He should be able to supervise and direct the work of others.

Grades of Superintendents Required.—All sewage treatment plants should be operated under technical control or supervision.

In the case of large plants, serving approximately 100,000 or more people and involving such treatment as by Imhoff tanks, sedimentation and separate sludge digestion, trickling filters or the activated-sludge process, Grade A Superintendents should be employed.

For moderate-sized plants, serving from approximately 50,000 to 100,000 people, Grade B Superintendents may be satisfactory; but for the more complicated plants it is desirable to have the operation supervised by a sanitary engineer or chemist who has the qualifications of a Grade A Superintendent.

In the case of less complicated plants, such as fine screening, serving less than about 50,000 persons, Grade C Superintendents may be satisfactory, provided there is adequate supervision by a sanitary engineer or chemist with the qualifications of a Grade B or a Grade A Superintendent. For small plants of a complicated type, or for dealing with difficult conditions, a Grade B or Grade A Superintendent may be required.

Compensation for Sewage Works Superintendents.—In order to attract and secure properly qualified men to act as superintendents their

compensation should be commensurate with their responsibilities. The Committee suggests the following relative salaries, based on common labor receiving a wage equivalent to 1.0:

Grade C Superintendent	1.0 to 2.0
Grade B Superintendent	2.0 to 3.0
Grade A Superintendent	3.0 to 5.0

This method of rating has been adopted because the scale of wages is not uniform in all places, and varies from time to time in the same locality.

The practice followed by some communities, of having a competent sanitary engineer to advise the officials regarding problems of sewage works operation, is a good one. This plan is especially desirable for a period immediately following the opening of a new sewage works. Where a community cannot afford to pay for the services of a full-time technically trained superintendent, it may be possible to unite with near-by communities in employing an experienced chemist or sanitary engineer for the supervision of operation, or it may be possible for a small municipality to secure the part-time services of a technically trained superintendent of some large sewage plant to supervise the operation.

School for Sewage Works Operators

Many of the operators and other assistants of sewage works, particularly at the small plants, lack the basic training which is necessary to understand the fundamentals of sewage treatment and to supervise and operate in a satisfactory manner the plants they control. A number of state departments of health are awake to this condition, and as a corrective measure there have been established in some states short-time schools, where instruction in the general principles of sewage treatment is given.

The need for this type of training is so great that additional schools should be provided. It would be desirable to have at least one school for each state, except where the number of sewage works is small, in which case it may be feasible to organize one school for two or more adjacent states. The various factors involved in conducting these schools will depend upon local conditions. The most important points to consider are the organizing and financing of the school, the character of instruction to be given, and the paying of the students' expenses.

State departments of health and sewage works associations are the logical organizations to establish and promote schools for sewage works operators. Where there is a suitable state educational institution conducting extension work, this is the most desirable place to conduct the school. As such institutions are financed by public funds only nominal fees would be charged. Students would thus have no great difficulty in paying for their instruction.

The general purpose of the course should be to train students in the fundamentals of sewage treatment and in making laboratory tests. The instruction should include lectures, laboratory work and inspection trips. The lectures should deal with elementary sewage plant design, and the fundamentals of hydraulics, chemistry and bacteriology. The scope of the laboratory work should vary with the length of the course and the previous training of the student. The most elementary course should include the keeping of records, the collection of samples, the measuring of settleable solids with Imhoff cones, the relative stability test, the determination of the pH of sewage and sludge, and the operation of chlorine apparatus. These studies may be supplemented, if time is available, or if an advanced course is given, by practice in the use of the chemical balance, the determination of suspended solids, dissolved oxygen, biochemical oxygen demand, and the numbers of bacteria and *B. coli*. The length of the course would have to be limited to a short period—preferably not less than one week. A two-week session would possibly be the maximum length of time that could be devoted to this work.

The method of financing the student's tuition and expenses will depend upon local conditions. In those municipalities where the officials are convinced of the importance of such schools it is possible that the major part, or perhaps all of the expense, will be borne by the municipality. Legal limitations governing the expenditure of municipal funds may be a controlling factor. In any event, the training received by the operator should increase his capabilities and add to the value of his services. The Committee recommends that the necessary expenses of sewage works operators for attending schools or conferences be paid by the municipalities.

Sewage Works Associations

Membership in sewage works association affords another means of acquiring valuable knowledge relative to the operation of sewage treatment plants. Several of these associations have been formed in a number of states or groups of states. These associations usually meet at least once a year for a two- or three-day convention when papers are presented, practical problems are discussed and inspections are made of plants of interest.

A Federation of Sewage Works Associations has been formed, which publishes the SEWAGE WORKS JOURNAL. This publication affords the sewage works operator an additional opportunity of familiarizing himself with problems relating to sewage treatment.

Some state departments of health are responsible for calling conferences of sewage works operators, for the purpose of promoting an exchange of ideas regarding sewage treatment problems and for improvement in economy and efficiency of the operation of sewage works within the state.

Analytical Determinations and Tests Required at Sewage Works

There are three main objects of making analyses and tests at sewage treatment works: (1) for control of operation; (2) for record of accomplishment; and (3) for research investigations.

The number and kind of analytical determinations and tests to be made will vary with the size and type of works. For small plants the routine tests may be confined to those required for the control of operation. For larger plants, especially where litigation may ensue, it is important to do more laboratory work than is required for the control of operation alone. Data should be obtained, not only for studying the efficiency of the plant, but also for comparison with similar data from other plants. At large sewage works, particularly where there are problems involving improvements or enlargements to the plant, or the recovery of by-products, research work should be carried on.

Research in the treatment of sewage and industrial wastes is greatly needed not only to promote economy and efficiency of treatment but also to determine ways of recovering valuable by-products. The analytical determinations and tests involved in research investigations are too varied to designate in this report, but will depend upon the problem being studied.

The analytical determinations and tests required for the control of operation and for a record of accomplishment may be classified according to the treatment provided. It is impracticable in this report to cover all kinds of sewage treatment, but some of the more widely used methods will serve for illustrative purposes.

Sewage Flow and Population Served.—It is very important that a continuous record of the sewage flow be kept. Where Venturi meters have not been installed, the use of weirs, or some other means, should be resorted to in order to determine the sewage flow. The quantity and time of bypassing sewage around all or any part of the sewage works, should be noted. During storms, the volume of storm-water which does not receive treatment should be recorded. Where an appreciable quantity of industrial wastes is treated, the volume, character and equivalent population load should be determined.

Screening.—For the control of the operation of screens, the quantity of sewage screened and the volume of screenings obtained should be determined. The time that the screens are in service, the work required on them and their power consumption should be noted.

For a record of accomplishment the screenings, where possible, should be weighed, and the water content determined. The amount of solids removed from the sewage can then be computed. The efficiency of screening in removing suspended solids is accurately determined by adding to the weight of suspended solids determined in the screen effluent

the weight of dry solids in the screenings from a corresponding volume of sewage, and computing the percentage of solids removed by the screens. By determining the loss or ignition of the suspended solids in the effluent and of the solids in the screenings, the percentage removal of organic matter can be estimated in a similar manner.

Sedimentation.—A minimum requirement for the control of treatment by sedimentation should be the conical measuring-glass test for the volume of settleable solids in the influent and effluent. The quantity of sewage and the volume of accumulated sludge are also important factors in the control of the treatment.

For a record of accomplishment the removal of suspended solids, by weight, should be ascertained by gravimetric determination of suspended solids in the influent and in the effluent. It is also important to determine the removal of organic matter. This may be done by determining the organic nitrogen or albuminoid nitrogen and oxygen consumed in the influent and the effluent. The reduction in biochemical oxygen demand has come to be considered an important index of the purification accomplished. Tests for dissolved oxygen in the influent and the effluent should be made with sufficient frequency to show whether the sewage has become septic.

Trickling Filter Treatment.—Relative stability tests of the effluent are desirable for the control of operation of trickling filters. The volumetric determination of settleable solids in the sewage applied and in the effluent is an index of the extent of the storage or unloading of solids in the filters. The volume of sewage treated by the filters and the condition of the filters with respect to clogging are also important factors in the control of operation.

For a record of accomplishment the reduction in organic matter can be ascertained by determining the organic nitrogen or albuminoid nitrogen and oxygen consumed, or of biochemical oxygen demand in the influent and in the effluent. The extent of oxidation is further shown by reduction in free ammonia nitrogen and increase in nitrogen as nitrites and nitrates.

Where trickling filter effluents are passed through sedimentation tanks, the same determinations should be made of the tank effluent as have been recommended for the filter effluent. The suspended solids in the trickling filter effluent and the tank effluent should be determined gravimetrically. The dissolved oxygen in the effluent before and after sedimentation will indicate not only the degree of oxidation but also the effect of the sludge in the sedimentation tank.

Activated-Sludge Treatment.—For the control of activated-sludge treatment, the flow of sewage, the proportion of activated sludge returned to the sewage, the volume of air applied and the amount of power used, are important factors. The proportion of activated sludge present can be

determined by sedimentation tests or more quickly by the centrifuge. A knowledge of the amount of solids in the sludge by weight is also important in the control of treatment. Tests for turbidity, suspended matter and relative stability should be made on the effluent after sedimentation. The sludge leveled in the sedimentation tanks should be kept under control by measuring the depth of sludge in the tanks and by observing the character of the sludge withdrawn.

For a record of accomplishment, in addition to these tests, determinations of total nitrogen or albuminoid nitrogen and oxygen consumed, or of biochemical oxygen demand, should be made on the sewage and the effluent. The extent of oxidation is indicated by determinations of free ammonia nitrogen and nitrogen as nitrates, and dissolved oxygen in the effluent.

Disinfection.—Tests for the control of disinfection should be made for residual chlorine after an adequate period of contact. For a record of accomplishment bacteria counts and *B. coli* tests should be made before and after disinfection. In some cases, it will be desirable to determine the reduction in biochemical oxygen demand accomplished by disinfection. The quantity of chlorine applied should be noted. For reasons of economy it may be desirable to vary the dosage of chlorine to correspond with the chlorine demand of the sewage.

Sludge Digestion.—For the control of sludge digestion the appearance and odor of the sludge and the reaction, or pH index, during digestion are important. Temperature is also important, especially where control is exercised over it. For a record of accomplishment the total solids and organic matter by loss on ignition should be determined of the raw and the digested sludge in order to ascertain the proper volume to withdraw. Where gas is collected, it is desirable to obtain its volume and composition. A record should be kept of the volume and character of the sludge liquor discharged from separate sludge digestion tanks.

Dewatering of Sludge on Sludge Beds.—When sludge is dewatered on sludge beds, the volume of sludge applied, depth of application, time of drying, number of applications per year, weather conditions and volume of dewatered sludge should be determined. Records of sludge bed operation should include the percentage of solids in the sludge as applied and as removed.

Mechanical Dewatering of Sludge.—Where sludge is dewatered by mechanical means, it is important to make tests of sludge density, or solid content, and reaction, or pH value, checked by rate-of-filtration tests in connection with the conditioning of the sludge for dewatering. The rate of dewatering by filtration of the sludge and the yield of cake are important. Determinations of the water and the solids in the dewatered sludge should also be made.

When sludge is dried and prepared for fertilizer, the determination of

its mechanical composition, percentage of moisture and of the total and available nitrogen and other fertilizing constituents is important.

Treatment of Sewage Containing Industrial Wastes.—Where industrial wastes or sewage containing abnormal quantities of industrial wastes are treated, analytical determinations and tests, in addition to those previously mentioned, may be required such as color, fats, alkalinity or acidity, iron, copper, lead, zinc, aluminum, calcium, magnesium, sulphates and sulphides, depending on the kinds of industrial wastes present.

Effect of Discharge of Sewage or Effluent on the Receiving Waters.—In many cases, especially where there is a possibility of litigation, tests should be made to determine the effect of the discharge of sewage or sewage effluent at different points on the receiving waters. These tests should ordinarily include color, suspended solids, dissolved oxygen and relative stability or biochemical oxygen demand. The presence of sludge banks should be noted. Periodic determinations of the number and kinds of plankton in the receiving waters may be desirable. In cases where the receiving waters are used for water supply, bathing or shell fish culture, bacteria counts and *B. coli* tests should be made. The time, extent and frequency of such tests will depend upon local conditions. In certain instances, particularly in tidal waters and lakes, studies should be made of the currents where sewage effluents are discharged. A knowledge is desirable of the dilution afforded by the receiving waters, particularly during the summer when temperatures are high and stream flows are at a minimum.

Importance of Sampling.—For comparative and analytical determinations and tests it is of the utmost importance that the samples be truly representative. In order to obtain representative composite samples individual samples should be taken at frequent intervals and in proportion to the sewage flow. Determinations of chlorine in the form of chlorides are of assistance in indicating to what extent samples are comparable.

Laboratories.—In order to perform the necessary analytical determinations and tests, it is essential that suitably equipped laboratories should be provided. The larger plants will require complete equipment for making analytical determinations and tests needed for research investigations, as well as for a record of accomplishment. In the case of small plants, it may be sufficient to provide equipment only for the tests required to control the operation. Where local laboratories are not available, control samples should be collected at regular intervals and analyzed by the technical supervisor.

Influence of Local Conditions.—It is impossible to stipulate just what analytical determinations and tests should be made at every sewage treatment plant. Local conditions will often govern. The analytical determinations and tests suggested in this report may be considered generally applicable. Other determinations and tests will be required in special cases.

In all instances it is desirable to record the temperatures of the sewage, effluents and sludges, in order to compare the results in different localities. Sufficiently complete analyses of the sewage should be made to determine its general character and composition.

It is unnecessary in this report to describe the methods of analysis which should be used. Technically trained men, having the control or supervision of the treatment plants, will know the methods of analysis and how to interpret the results.

Operation and Maintenance Cost Data

In addition to complete records of operating and analytical data, operation and maintenance costs should be kept at sewage treatment works. These costs should be segregated into labor and materials. Moreover, it is desirable to keep operation and maintenance costs separate, with a further record of the cost of all new additions or improvements. Should any money be collected from the sale of screenings, sludge or other materials, the amounts should be recorded. At the large plants it is desirable to make a further segregation by keeping separate accounts of the cost of screening, sedimentation, sludge treatment, etc. A record should be made of the sewage flow and the population served so that costs of treatment per unit volume of sewage and per capita can be calculated.

As improvements are made to the works from time to time and as old units are abandoned, the cost of these should be added to or deducted from the first cost of the plant so that the fixed cost, comprising the interest on the investment and depreciation, can be determined.

Reports Covering Sewage Works Operation

In spite of the large number of sewage works of considerable size in the United States, the number of these is remarkably small, at which printed reports giving operating data are prepared. These reports are of much interest and value to all those engaged in the design, construction or operation of sewage works. It is mutually helpful for sewage works superintendents to exchange reports. It is therefore highly desirable that printed reports be prepared, preferably annually, giving the operating and cost data of sewage treatment works, particularly in the case of works of any magnitude. The yearly budget, which provides for the cost of operation, should include an item covering the printing of an annual report. It is also very desirable that articles relating to sewage works operation be published in engineering magazines or journals.

Experience with Small Pumping Stations*

BY HARRY W. EUSTANCE**

I wish to acknowledge that John Woodford, Ithaca's Superintendent of Sewers, of more than thirty years' service, has furnished much of the information that is the basis of this paper. Mr. Woodford has been in charge of the operation of Ithaca's sewerage system since it was turned over to him upon completion of the original installation by Prof. H. N. Ogden, Chief Engineer for the construction. Since 1898 it has been Woodford's job to keep things running, and "things" include sewage pumps as well as the sewage itself.

Our pumping installation in Ithaca consists of two low-lift stations, a small one on Titus Flats serving about 5 per cent of the city, and a larger one on Buffalo Street, serving about 33 per cent. There is then the main pumping station, where all of the sewage must be lifted from mains sixteen feet below ground, and pumped to the disposal works.

We shall discuss briefly the different installations that have served us and the trouble experienced in their operation. The original installation at the pumping station consisted of two steam-driven centrifugal pumps of about 1500 g. p. m. capacity each, operating at low speed. Only the larger lift station then operated, and this with a Shone ejector using compressed air produced in the main pumping station $1^1/_2$ miles away.

I am sorry that I was not acquainted with this original installation, for the pumping station must have been a grand sight with polished brass on engines and compressors.

With this outfit, however, they experienced operating troubles. The greatest, as might be expected, were expenses for fuel and three shifts of operators.

The pumps had to be cleaned every day, a job requiring about one-half hour per pump. The slow-speed pumps were not troubled so much with rags as they were with the antique beer corks. Another big difficulty with the original installation was the fact that the compressed air was generated at the main pumping station and transmitted such a long distance through a six-inch pipe, with lead joints, before it was used. It was pretty hard work to keep from losing most of the air before it reached the ejector, and Mr. Woodford tells that they used to relish a good flood once in a while that would cover the ground with 6 inches to 2 feet of water. His outfit would then get out in the water and mark the places where air bubbles came through the water from the pipe line. They would repair it when the flood receded.

* *Presented before the Second Fall Meeting of the New York State Sewage Works Association, Syracuse, Sept. 13, 1930.*

** *City Engineer, Ithaca, N. Y.*

The ejector itself worked without any trouble from clogging; in fact, it gave little or no trouble except when overloaded. During wet weather, due to leaky sewers, the heavy flows would keep the ejector tripping about once a minute. Under such conditions trouble would be experienced with the air cylinder, which had to be cleaned four or five times during the day and night.

The second installation of pumping equipment was made when it became necessary to sewer the area known as Titus Flats. A lift station was constructed; instead of installing ejectors, a centrifugal pump, electric powered, was tried. This pump was designed to pump water, not sewage, and was installed in a wet pit. Trouble commenced with the first turn of the pump. The pump would soon become clogged, and what a job it was to clean it! It was at the bottom of the wet pit; valves had to be closed, sewage removed from the pit with a diaphragm pump, and the settled solids on the floor and pump scraped up and buried. Before the installation was modified by elevating the pump above the floor of the pit, so that the pit did not have to be drained every time it was cleaned, Mr. Woodford admits that there was not an available square foot of land remaining in the vicinity in which he could bury the solids so removed. This installation has since been further altered, a new pit constructed, and a sewage pump installed in a dry well. We still have, however, as much operating trouble with this outfit as with any other on account of the small size of the pump, which is four inches in diameter. This pump has to be cleaned every week or so during the year.

Mr. Woodford has outlined to me his method of cleaning these vertical centrifugal pumps. He says it is most important to keep the pits clean, because it is necessarily a dirty job at the best and the operators are more apt to slight the work if they have to do it in dirty and greasy surroundings. He keeps the pump pits clean by hosing regularly and scraping up all oil on the floor. Pumps, floors and walls are scrubbed at longer intervals with kerosene.

To begin the operation of cleaning, he first pumps the water below the level of the pump, if practicable. Then he is sure that there are no injurious gases in the pit, testing if suspicious with a gas lamp, and if necessary lowering an electric fan into the pit to clean it of gas. After shutting off the power he puts a danger signal on the switch, so that the power cannot be thrown on during cleaning operations. He closes the inlet and outlet valves and removes the gland in the stuffing box. Upon taking the bolts out of the removable top plate he inserts screw eyes in the bolt holes and raises the plate with a small chain hoist. Rags caught by the runners are removed with cleaning hooks; usually two men are needed for the job. Some rags remain immediately under the runner. In order to remove these rags the pump is started with the plate still up and no water in it. The heat

from friction soon dries the rags and they fly out from under the runner. This is the only way to remove them easily. The pump can then be reassembled.

In 1919 the local electric company finally convinced the City Council of the saving that would result by replacing the old steam pumps at the main pumping station with an electric outfit. This was done, resulting in an amazing saving in operating cost and much less trouble in pump operation. Also much valuable space in the pumping station was converted to other use when the boilers, engines and compressors finally went. But upon installing the electric pumps, which are vertical centrifugal outfits located in dry wells, our present type of operating difficulties developed. These have been mainly the clogging of the pumps, which have been attended to as above outlined. No flow meters were present at this installation and we do not have them now at the lift stations. Inspection reveals that a pump is clogged if it binds when the shaft is turned by hand; or a kilowatt indicator, varying from its usual registration, will show that there is trouble.

With our electric installation controlled with float switches it has not been necessary to keep a man at the stations continuously. The pumps are visited three or four times during the day and once at eleven o'clock in the evening.

In 1928 the pumps at the main pumping station needed much repairs, and their capacity was insufficient to handle the flow in wet weather. A study for a new installation was made, with the attempt to get a pump relieved as far as possible from the disadvantages of the existing outfits. Wood-Trash pumps, manufactured by the Fairbanks-Morse Company, were chosen to carry the average flow. There are two 10-inch pumps, each of about 2500 g. p. m. capacity. We also put in a third of 3500 g. p. m. capacity for use during flood flows. This was manufactured by the Yeomans Bros. Company. Both makes of pump are of the non-clogging variety and pump the sewage, after being screened only through a $2^1/_2$-inch bar screen, with no clogging whatever. In twenty months since their installation none of them have been down for cleaning. We are quite satisfied with the way we have reduced that unpleasant job. The same cannot be said, however, of a smaller pump installed at the same time to pump sludge. This was a 3-inch non-clogging pump operating at a high speed, 1700 r. p. m.; and, of course, it had very heavy duty to handle sludge, but it required much attention due to clogging. It was in operation about one hour per day. If it would get through this hour without having to be cleaned, the operators would celebrate. It has since been shut down, however, and will be replaced.

One item that appears to us to be lacking from the products of sewage pump manufacturers is a small capacity centrifugal pump. The use of

screens is practically out of the question in an automatically controlled lift station, and a large capacity pump floods most existing discharge mains. The small capacity pumps that are offered have usually small openings and run at high speed. Our suggestion is a pump having large openings and running at a much lower speed to balance up the capacity.

Mr. Woodford has devised an automatic air-relief valve which is installed on all of our pumps. Our pumps are located in dry wells adjacent to the sewage pumping pits, and the head of the sewage on the pump varies from higher to lower than the elevation of the pump casing. So when the pump lowers the sewage and then shuts off, air enters, which has to be removed before the pump starts, with the sewage at the high level. The valve we use is built of two halves of a $^3/_4$-inch water meter casing. In this is a closet float of composition material. Attached to the float is a vertical rod having at its top a vertical check valve. The operation of these has been perfectly satisfactory and we have nowhere found where satisfactory ones can be purchased from stock.

Discussion

Mr. A. G. Card, of Syracuse, stated that lack of supervision was the most important cause of difficulty at the East Syracuse sewage pumping station. The alemite pressure lubrication system was very successful at this plant. The necessity of having a supply of water for cleansing purposes was indicated. An air-relief valve should be used on all force mains.

Mr. A. S. Bedell, of Albany, asked whether those present had secured satisfactory results with small motor-driven centrifugal sewage pumps mounted on pre-formed steel pump wells and pump pits. Mr. Biele stated that such installations were satisfactory. He urged that no check valves be used in order that reversed flow will occur when pumps are stopped, thus flushing screens and pumps.

Mr. W. A. Ryan, of Rochester, stated that a horizontal-shaft, motor-driven centrifugal pump was preferable to the vertical-shaft type. He requested a discussion of the relative value of controlling motor-driven pumps by floats and mercoid controls. The possibility of using portable mud-hog pumps in case of breakdown of small pumping stations was indicated as being an economical substitute for duplicate equipment.

Mr. Wellington Donaldson, of New York City, stated that 3-inch trash pumps at Middletown, N. Y., clogged when the fine screens had to be cleaned. One and one-quarter inch screens gave protection, although 3-inch bar screens were not satisfactory.

Mr. Woodford, of Ithaca, stated that large trash pumps were satisfactory but that small ones gave trouble from clogging, which was indicated by an increase in the power consumption.

Mr. W. P. Gyatt, of Syracuse, stated that large wet wells act as sedimen-

tation chambers and that the sewage first pumped from the well consists largely of sludge. He, therefore, advocated the use of as small a wet well as possible.

Mr. Harry Eustance, of Ithaca, stated that the use of a Venturi meter to indicate pump capacity had permitted prompt cleaning of pumps and a saving of 40 per cent in power. Hand spinning of centrifugal pumps is not a reliable way of determining undue friction, because a partly clogged pump will spin freely at slow speed.

Mr. F. A. Cary, of Fairport, stated that float controls had to be installed in place of mercoid controls.

Mr. E. R. Cotton, of Buffalo, stated that an investigation of mercoid controls had indicated that 2-inch air pipes, such as used at Fairport, were not large enough, and that an air pipe with a diameter of at least 3 inches is needed. He discussed the great importance of providing pump manufacturers with data as to the variation in head to be expected.

Mr. F. J. Biele, of Freeport, suggested that the check valve be left off the discharge pipe of centrifugal pumps so that the reverse flow would occur when the pumps were stopped, which would automatically flush the pumps.

Mr. H. H. Chase, of New York City, stated that the coefficient "c" of cast iron force main for sewage was 60, thus giving greater capacity than with water, due to greasy coating of pipe conducting sewage.

Mr. W. A. Ryan, of Rochester, said that wet wells should be flushed with a fire stream at intervals to remove settled solids and that chloride of lime could be used to suppress odors.

Mr. John Woodford, of Ithaca, intimated that no one should expect small centrifugal sewage pumps to be efficient. Ample screen area is needed to protect the pump and yet not offer great resistance to the flow of sewage. Rigid shafts should be provided and dangerous projecting nuts on the couplings of the shafts should be avoided. It is best when designing centrifugal pumps to have the shut-off at 50 per cent of the maximum capacity of the pump, in order to avoid overloading the pump when it is started.

Sludge Disposal at Brockton, Massachusetts*

BY FRANK A. KENNEDY**

In common with the experience at most sewage disposal plants the question of sludge and sludge disposal is the paramount one at Brockton. Thirty-four years ago our sludge was disposed of by drying on sand areas; after considerable experimenting with various methods of disposal, the sludge is today being treated in the same manner. When the plant was first put into operation it was thought that the sludge question could be handled in the receiving reservoir at the pumping station. The capacity of the reservoir was 500,000 gallons and it was anticipated that it be used as a septic tank. It did not take long, however, to learn this method was not practicable. The method of procedure at this time (1896–97) was as follows:

The entire sewage flow passed through the receiving reservoir and received, according to the rate of flow, a varying degree of sedimentation. There were two pumpings a day, one in the morning, and one in the afternoon. In the afternoon pumping the sewage was drawn down to the sludge line. At this point the sludge was agitated by sewage discharged through perforated pipes lying on the floor of the reservoir. The agitation was done by reversing the flow of sewage through these pipes and thereby stirring or agitating the sludge until it was in a condition to be pumped to the sludge area. The sludge thus pumped was allowed to remain in the force main, a three-mile, 24-in. cast iron line, over night. On the resumption of pumping the following morning the sludge in the force main was forced through to the disposal area and placed on one of three acres of sand used for this purpose. After drying, the sludge was raked into piles and burned. Although this method of disposal was quite satisfactory as far as getting rid of the sludge was concerned, a nuisance was created by the smoke which caused complaints by dwellers in the vicinity of the plant, so that the method was abandoned in 1899.

During the year 1900, with a total flow of 248,807,000 gallons of sewage, about 1143 tons of dry sludge were removed from the beds. The composition of the rakings varied with the season, the moisture ranging from 5 to 50%, sand 35 to 85%, and organic matter 10 to 20%. It was estimated at this time that the market value of the fertilizing ingredients in the sludge was from $4 to $5 a ton. An average of several analyses of the rakings was as follows:

Water	18.30%
Phosphoric acid	0.91
Potassium oxide	0.52

* *Presented before the Second Fall Meeting of the New England Sewage Works Association, Fitchburg, Mass., Oct. 15, 1930.*

** *City Chemist.*

Nitrogen	1.35%
Calcium oxide	0.33
Insoluble matter, sand, etc.	65.50

During this period the sludge was being sold to the highest bidder for about $150 per year, farmers in the vicinity of the plant being the bidders. Although the return was very small it was a means of getting rid of the waste. One difficulty was encountered, however, and that was that the farmers could not seem to haul the sludge away at times best suited for the department.

In 1906 a contract was made with the manager of a large farm and estate quite near the plant, to take the sludge when requested. In about two years' time the management of the farm was taken over by a new man who apparently did not value the sludge as a fertilizer and the agreement ended. From that time on, fewer and fewer of the farmers availed themselves of the privilege of taking the sludge, due to the fact that the entire locality near the plant is of sand formation and although the sludge had fertilizing value it was impossible to remove it from the beds without rather a high percentage of sand, which the farmers did not care to add to their own sandy areas. Another reason for the non-removal of the sludge was that the amount received at the beds had so increased that there were not farmers enough to handle it. The sludge removed had increased from 72 tons during 1896 to 3422 tons in 1907. This was a period of rather rapid increase in population in Brockton and we were becoming hard-pressed for filtering area at the disposal plant. Additional beds were built but not enough to keep pace with the increasing flow of sewage.

In an endeavor to help our sludge problem a new scheme was adopted. It consisted of the installation of a revolving screen at the pumping station for the purpose of removing the suspended solids from the sewage. The device was of the Weand type, comprising a cylindrically shaped framework about 12 feet long and 4 feet in diameter, covered with a very fine-meshed screen of monel metal. A screw-shaped carrier extended through the center of the screen from end to end, for the purpose of catching and conveying the screened suspended matter to the outlet end. The sewage was introduced at the inlet end of the screen, which revolved on its longitudinal axis. The deposit or screenings were caught in gunnysack bags and centrifuged in order to reduce the water content to a minimum. After centrifuging, the suspended matter was mixed with soft coal and burned in the steam boilers used to operate the pumps. The engineers objected strenuously to the procedure, claiming that the material from the centrifuge could not be burned satisfactorily enough to maintain a proper head of steam. There has always been, however, a suspicion in the minds of the department heads that it was a question more of distaste for handling the material on the part of the engineers and firemen than anything else. The

screenings were finally disposed of by burying and the same condition was experienced as at other plants, namely, that the buried material consisted of a sour, putrid mass even after a period of two to three years.

The screen removed an average of 2000 lb. per day of suspended matter but it was becoming evident some other method of sludge disposal must soon be adopted. The cost of maintenance of the screen was altogether too high, due chiefly to mechanical imperfections causing almost constant repairs. Another difficulty experienced was that, owing to the fact that the screen had to be installed at a point 10 or 12 feet above the main outfall sewer, it was necessary to pump the sewage this distance onto the screen. The effect of pumping and discharging the sewage at considerable speed tended to break up the suspended matter and force much of it in a finely divided state through the meshes of the screen. The result of this was that the surfaces of the sand beds became impregnated with this more or less colloidal material, which necessitated the removal of about six inches of material from the surfaces of the beds in order to get them back to normal.

Owing to the installation of our first unit of sprinkling filters in 1912, it became necessary to pump continuously. The sewage was still being carried through the reservoir, and in spite of some suspended matter removal by the screen, considerable amounts were getting into the reservoir, which had to be cleaned periodically. Of course, as the pumping was continuous, the old method of using the agitator daily had to be abandoned. It was during this period that most of our experiments were made. The long detention of the sludge in the reservoir caused the sewage to arrive at the plant in a septic condition and absolutely devoid of oxygen. Therefore, our first endeavor was to try some means whereby we might introduce oxygen. A 10 by 10 by 10 ft. wooden tank was constructed, as a somewhat modified type of the Clark slate bed. Cobble-stones were used instead of slate and the sewage was introduced over corrugated-iron runs each 10 ft. long and $2^1/_2$ ft. wide. It was pumped at such a rate that it received twenty aerations. This experiment was run from early spring until late fall and even after many changes in rates of flow, etc., never once did we obtain free oxygen.

The tank was next converted into an activated-sludge tank and the experiments were continued over a period of two years. The results obtained were remarkable, with regard to the clear sparkling effluent which was obtained, but our old bugaboo, sludge, again defeated this attempt. The sludge upon being drawn onto especially constructed drying areas acted very queerly. A certain amount of the water appeared to filter off quite rapidly and then to cease filtering just as rapidly. A crust would form upon the surface of the remaining sludge and would remain in this condition almost indefinitely, with very little odor. Upon being disturbed, however, for removal purposes, it was found that the sludge re-

sembled a gelatinous sandwich, with the surface of the bed on the bottom and the crust on top. The odors were overpowering and could not be overcome.

Experiments with Imhoff tanks gave almost the same results. Probably because of some of our particular industrial wastes, Brockton sludge does not seem to lend itself to digestive action with any great degree of success. Gasification and digestion experiments by other parties, namely, by the State Department of Health Laboratory at Lawrence and by Prof. Gordon Fair of Harvard University, seemed to lend credence to this theory.

With the unsatisfactory conditions existing at the pumping plant from the viewpoint of sludge disposal it was decided to abandon the Weand screen and reservoir and transfer the whole problem to the disposal plant. With the addition of an acre and a half of sprinkling filter, a preliminary sedimentation tank was constructed. This tank, divided into three compartments, gives an hour and a half detention at a 5,000,000 gallon rate.

The sewage is now pumped directly from the main outfall sewer to the preliminary settling basin. Whatever compartments are used are cleaned weekly. Each compartment is 22 by 50 by 12½ ft. and has an average of about 3 feet, or 25,000 gallons, of sludge. After the supernatant liquor has been drained off, the sludge is hosed to the outlet lines, where it flows by gravity to the sludge-drying areas. Last year 2,429,627 gallons of sludge was drawn onto the sludge beds. The average results of analyses of this material were as follows:

Specific gravity	1.019%
Moisture	93.78
Organic	5.22
Inorganic	1.00

The sludge is applied to three acres of sand, which are cleaned, except in winter, after each second dose. The sludge dries quite rapidly under ordinary conditions, because the area available allows the sludge to be spread in a rather thin layer. Very little nuisance is created, except in warm damp weather, when we have found that odors can be kept at a minimum by addition of ½ barrel of ordinary chloride of lime, added at intervals as the sludge is being applied. The sludge from the preliminary tanks drys in sheets and can be handled very easily with dung forks when reduced to anywhere from 70 per cent to 50 per cent of moisture. The dry analysis for the sludge removed last year was as follows:

Cubic yards	3.165
Moisture	40.69%
Organic	13.84
Inorganic	45.47

Sludge from the secondary settling basin presents a little more of a problem than the preliminary tank sludge during certain seasons of the year.

During the spring and fall, or when the sprinkling filter is unloading, vast numbers of *Tubifex* worms appear in the sludge, thereby tremendously retarding the drying. The secondary sludge dries differently than the preliminary, in that it curls up in small pieces rather than in sheets. It is more humus-like and when devoid of worms has no odor. For 1929, 539,266 gallons of this sludge were dried. Analyses of the dried sludge were as follows:

Cubic yards	670
Moisture	19.76%
Organic	15.17
Inorganic	65.07

All of the dried sludge at the present time is used to fill low land adjacent to the plant, and in spite of long years of endeavor we are still seeking some method of reducing our sludge bulk in order to facilitate its disposal. In spite of our apparent inability to reduce the amount of sludge by digestion or otherwise we feel that the problem is being handled in a satisfactory manner. With the exception of times of damp, muggy weather, and when the sludge is in a fresh condition, there is very little odor at any distance from the plant. This fact is brought out on account of the lack of complaints from neighbors living in the vicinity of the disposal area. The underdrains in the beds have been raised to an average depth of $2^1/_2$ ft. from the surface, so that, except in wet weather, the sludge dries very rapidly. The filtered secondary settling basin sludge upon being dumped seems to disintegrate very quickly, so that in comparatively few weeks all that remains is the sand which has been removed from the beds in the process of cleaning. Glass-covered beds have been more or less successful at some plants, but after all is said and done sludge beds of an acre area, in order that the sludge may spread in shallow layers, works out very well for us. Our problem today is to find a place to dispose of the sludge after it is dry and inoffensive.

Handling of Screenings at Long Beach*

BY HERBERT PATERSON**

Briefly stated, screenings are handled at Long Beach screening plant as follows:

The solids retained by the Dorr screens are caught in perforated buckets on a slow-moving elevator and dumped into a pneumatic ejector, from which they are raised by compressed air to a covered measuring hopper above the incinerators, and after being weighed are again blown by compressed air directly into the furnaces and there burned.

The journey from the screen pit to the ejectors is made on an endless chain of perforated buckets traveling at a rate of 12 ft. per min. This slow speed affords an opportunity of draining the water off, although the transfer only takes $1^1/_4$ min. and is the only time during which the screenings are exposed to the air. It is to this short exposure that we attribute the small amount of odor which is to be found around our disposal plant.

It might be well to mention here our method of cleaning the screens. Formerly the slots, which are $^1/_{16}$ in. wide by 2 in. long, would gradually clog up on the under side, with the grease in the sewage retarding the flow and decreasing the amount of water handled through the screen. It was necessary once a week to take the screen out of commission and thoroughly clean it with a wire brush on the spindle of a portable grinder, a day's job for an 8-ft. screen.

We have now installed over each screen a 2-in. water line with a short length of hose and a nozzle working under a 60-lb. pressure.

By directing this jet over the screens at night when the flow is low and the water pressure high, we are able to operate for 60 days without wire-brush cleaning.

From the elevator buckets the screenings are dropped into a pneumatic ejector pot which holds 1000 lb. of screenings. When the pot is full the lid is closed by a hand lever, compressed air turned in and the screenings are blown through a 6-in. cast-iron pipe to the weighing hopper on top of the furnaces, a lift of about 18 ft. This weighing hopper is a circular steel tank with a sealed cover and has a capacity of 5 tons.

When the contents have been weighed, compressed air is turned on and the screenings blown directly on to the furnace grates. The size of the charge varies with the time of day and the quantity of sewage flow. It will be readily understood that when one charge is completely destroyed, another charge must replace it immediately in order that the furnace does

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** *City Engineer, Long Beach.*

not stand empty. Consequently, the charges vary in size. A fair sized charge is 3000 lb., which will take about 4 hr. to burn. At present we are handling about 9 tons of screenings per day in 6 charges.

Our daily flow of sewage is 10,000,000 gal. and the amount of screenings fluctuates from 1850 to 2350 lb. per million gallons, the average being 2100 lb., with a moisture content of 90 to 92 per cent; and the yield of ash after incineration 50 lb. per million gallons or $2^1/_2$ per cent of the weight of the screenings burned. The incinerator is constructed with grate bars in the front half of the furnace and a solid floor in the back half. Two Premix gas burners under air pressure enter the front end of the furnace. The burning is entirely from the top and the method is as follows:

The fresh charge lies on the grate bars, draining and heating for approximately 30 min.; the water drained being returned to the screen pits. As the top begins to burn, the operator pushes it back onto the solid floor, working off the top every 30 min. until the whole charge is completely burned up.

The ashes are then removed before a fresh charge is inserted. The burning is continuous throughout the twenty-four hours and there are two furnaces, one in operation and the other being a standby.

The ash has some value as a fertilizer and is entirely used on the gardens surrounding the plant. The Park Board is also glad to get it and many private citizens come with sacks and take away a small quantity for their private gardens.

A chemical analysis gives the following results:

Phosphoric acid	4.07%
Potassium oxide	0.35
Ammonia	0.54
Or a total fertilizer value	4.96

With this system we are able to burn 1 lb. of screenings with $1^1/_2$ cu. ft. of gas. It is to be noted, however, that our gas is natural with a heat value of 1200 B. t. u.

The cost of incineration of screenings is difficult to estimate closely. The men who attend to the furnaces do other work and the gas cost in our particular case is low as the city owns the gas system. The closest approximation I can make is as follows:

Daily consumption of gas—24,000 cu. ft. @ 15¢	$3.60
Energy of blower per day	0.50
Wages—$^1/_3$ of 1 man's time for 3 shifts	6.50
Total outlay	$10.60
Amount of sewage handled—10,000,000 gal.	
Cost of incineration per 1,000,000 gal. of sewage	$1.06

or practically $1.00 per ton of screenings.

In conclusion, the incineration of screenings, while more costly than other methods of disposal, is a clean and sanitary method. The screenings are disposed of without offense, nuisance or menace to health. It utilizes a smaller space than any other method and there is no residuum to be taken care of. At present the daily sewage flow is about 10,000,000 gal., consequently our bill for incineration amounts to $3900 a year. It might be possible to save one-half this sum by changing the system, but it is so satisfactory in the location at our disposal that I doubt the advisability of making any change, at least until a completely new form of sewage treatment is installed.

Odor Control by Chlorination*

BY L. L. ROSE**

During recent years there has arisen, in connection with the operation of various sewage treatment plants, a considerable amount of trouble from odor nuisance. The problem is frequently one of operation, but recent developments have indicated that much of the difficulty can be anticipated and practically eliminated.

The many different odors emanating from sewers and sewage treatment plants are frequently caused by various gases from industrial wastes. The most serious, from the standpoint of odor nuisance, is hydrogen sulphide.

Hydrogen sulphide gas is very volatile, foul smelling and far reaching. It can be dissipated and carried for great distances by light winds, and is very disagreeable when present in even small quantities. The nuisance is greatest at night, when becoming cooled, the gas lies close to the ground and is rolled along and spread over large areas. This gas tends to follow valleys and depressions, becoming quite obnoxious to people whose homes are in its path, and neighbors are generally resentful of the odors and even of the works themselves.

Important factors to be considered are: the time of concentration of sewage, which may be increased by long laterals and mains; flat grades; obstructions or accumulated solids in the sewers; or intermediate lift stations. Contact with relatively stagnant sewage or with masses of decomposing organic matter in the collecting system results in a seeding of the fresh sewage, with the consequence that septicization occurs much sooner than would normally develop under good conditions.

When sewage is collected in a wet well and pumped after it reaches the plant, the retention period in the well allows additional time for the sewage to become more septic. Particularly is this true if the well is irregular in shape, permitting sewage solids to collect in the corners or around the edges. Such a condition in the pump pit could be anticipated and eliminated by building the bottom of the collecting well on a good grade, sloping toward a small sump, in which the pumps have their suctions, and so designed that dead spaces are excluded and the entire floor scoured each time the sewage is pumped. Thus quite frequently it is possible to reduce odors by changes in the plant.

The most practical means by which odors may be eliminated is the use of chlorine gas to control the rate of multiplication of the hydrogen-sulphide organisms. Chlorine, which is a powerful disinfecting agent, does this very

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** *Assistant Engineer, Bureau of Engineers, City of Los Angeles.*

effectively. It not only kills the hydrogen-sulphide organisms present in the sewage and retards their subsequent development, but when hydrogen sulphide has already been produced ahead of the point of chlorination, the reaction is one of odor destruction.

With these thoughts in mind, plans were made to control the odor present at one of the pumping plants of the city of Los Angeles, on Manchester Avenue, near Figueroa, which was placed in operation in January, 1921. At that time this plant was somewhat isolated, but with the march of progress it is now surrounded with modern markets, bungalows and apartments.

The pump well in this plant is circular, with a diameter of 24 ft. The sewage enters the plant 20 ft. below the ground level through a coarse bar screen, flows along entrance channels and drops 10 ft. into the wet well below.

Two vertical sewage pumps, each having a capacity of 1800 g. p. m., with their suctions 8 in. above a small sump, lift the sewage through a force main into a trunk line which delivers the sewage to the treatment plant at Hyperion.

The sewage inflow at the pumping plant is 2,000,000 gal. per day, and fills the pit in 12 to 15 min. Therefore, during filling and pumping periods gases are released into the atmosphere with a resulting odor nuisance.

To combat this odor a solution-feed chlorinator was obtained, and experiments to control the odors were started in February, 1930.

A small limestone tower was used, built from a barrel and filled with $^3/_4$-in. crushed limestone, weighing 92 lb. to the cubic foot. A solution line from the chlorinator entered the barrel through the bottom. Water was fed to the tower under 20 to 40 lb. pressure, mixed with 8 lb. of chlorine, which acted on the limestone and produced hypochlorous acid. This mixture was fed through hose and hard rubber pipe to the pump pit and dry well where it was released through hard-rubber sprays, two in the pump pit and one in the dry well—the three feeding $4^1/_2$ gal. of liquid per minute. These sprays atomized the acid and filled the chambers with hypochlorous gas, which is quite destructive to metallic surfaces. This gas killed the odors fairly well, but not completely, so a vent from the top of the pump pit was carried to a point 150 ft. back of the plant. Fumes were carried through a 12-in. vitrified clay pipe to a stack 30 ft. high, with a gas burner in the bottom. Gas was burned to consume as much of the odor as possible, but principally to heat the escaping gases so as to help them rise to a greater height. On an average, 500 cu. ft. of gas was consumed in 24 hours.

The results of these experiments were so encouraging that the city purchased a new chlorinator in July, which is more modern and far more efficient. New sprays were installed and the limestone tower was placed on

the roof, which produced more pressure at the sprays and released more hypochlorous gas. After these sprays were put in use, the odors were practically controlled. Some of the people who had previously complained now stated that the odors were no longer noticeable.

Lead acetate test papers were used to detect the presence of hydrogen sulfide at three or four stations throughout the plant, while the chlorine or hypochlorous gases were detected by iodine and starch test strips. Most of the hydrogen sulphide detected was directly under the top floor and in the building.

At present the old wooden floor is being replaced by one of concrete, and while the pits are exposed, the chlorinator is delivering 15 lb. per 24 hours, and test papers show no hydrogen present in the building. Tests taken at the stack show a trace of sulphide, so it is being considered to wash the gases in a specially constructed chamber before they enter the vent stack.

In addition to the foregoing, the wet well is washed out once a week by a crew of men, to get rid of any solid matter that may have lodged on the bottom. The sides and top of the pit are also scoured at that time.

The cost of treatment at present is $1.25 per day or $0.63 per million gallons. The limestone used averages two pounds per day.

Summary

1. Objectionable odors from sewage plants are caused chiefly by hydrogen sulphide.

2. The production of hydrogen sulphide occurs in sewage having a high sulphate content, and is facilitated by long laterals and mains having flat grades, and in other places by contact with accumulated masses of decomposing organic matter or mixing with septic liquor.

3. Odors can frequently be materially reduced by correcting conditions at the plant.

4. Chlorine destroys hydrogen sulphide in definite proportions, thus helping to destroy an odor nuisance.

5. Definite odor reduction can be obtained.

6. Odors are most severe in the evening, from sundown to 10 P.M., and the maximum dosage should be maintained during these hours.

7. Hypochlorous acid is very destructive to metallic surfaces, and all metal that it comes in contact with should be protected.

Discussion

BY L. H. ENSLOW*

Mr. Rose has presented a very interesting description of the experimental application of hypochlorous acid as a means of destroying odors emanating from sewage. Chlorine water first applied from the spray heads

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was objectionable because of its irritating effect on the eyes of the operators and the likelihood of corrosion difficulties.

The experimental application of hypochlorous acid produced by a modification of the well-known "Kellner Process" was an attempt to destroy odors without the objectionable features attendant upon the chlorine-water process.

The "Kellner Process," developed and patented in Austria in 1894, consisted in passing chlorine gas upward and water downward through a tower of crushed limestone. At the Manchester avenue station chlorine water from a chlorinator entered at the bottom of the tower and was discharged at the top. In this procedure the chlorine is converted to hypochlorous acid and calcium chloride in accord with the following reaction, which in practice requires roughly 0.9 lb. of limestone or marble per pound of chlorine fed.

$$2Cl_2 + CaCO_3 + H_2O = 2HOCl + CaCl_2 + CO_2$$

The extent to which this reaction proceeds to completion is dependent upon such factors as time of contact between chlorine water and limestone, temperature, quality of limestone and surface of limestone exposed. In making use of limestone towers for hypochlorous acid production a material of high purity (approximately 98% $CaCO_3$) and small size ($^1/_4$-in. diam. or finer), as recommended by C. T. Henderson, appears to be a very satisfactory material.

Hypochlorous acid when sprayed through the atmosphere above the sewage will react with ammonia and other gases there present. Sulphur-bearing compounds are destroyed and ammonium chloride and chloramines are produced in accordance with the following reactions:

$$(a)\quad H_2S + HOCl = H_2O + HCl + S$$
$$(b)\quad NH_3 + HOCl = NH_2Cl + H_2O$$
$$(c)\quad NH_3 + 2HOCl = NHCl_2 + 2H_2O$$

The important reactions are (*a*) and (*c*), although (*b*) may to a limited extent take place. Excess hypochlorous acid breaks down to produce nascent oxygen and hydrochloric acid which in turn reacts with ammonia to produce ammonium chloride.

$$(a)\quad HOCl = HCl + O$$
$$(b)\quad NH_3 + HCl = NH_4Cl$$

To avoid completely every corrosion difficulty inherent in the use of hypochlorous acid it may prove advantageous to substitute calcium-hypochlorite solution produced continuously, if possible, by mixing chlorine and lime emulsion. In this case the continuous feeding of hydrated lime replaces the limestone in the reaction tower. The location of the spray heads will be important because the air must either pass through, or mix with, the spray of hypochlorite at some point, if deodorization is to be complete.

Probably the most efficient and economical scheme, in many instances, will be to vent the wet well through the roof and place the spray nozzles within or across the entrance to the stack. The regulation of proportions of lime to chlorine need not be exact. Ordinarily it is desirable to feed from 1 to 1.25 lb. of lime per pound of chlorine applied.

The use of hypochlorous acid sprays for odor control at this Los Angeles pump station has been an interesting innovation and constitutes a promising development. So far the indications are that the corrosion difficulty justifies additional experimental work with finer limestone or hydrated lime. One or the other should materially improve the practical aspects of the process if it does not increase the efficiency of odor control.

The correctness of this assumption is attested to by the records of performance during the first few days after the installation of the original limestone tower (February, 1930) by F. A. Batty, assistant chief engineer in charge of pumping stations and outfall sewers, under the supervision of J. J. Jessup, city engineer. After the "fines" in the ungraded limestone had been consumed, the remaining material—$^3/_4$ in. or larger—reacted very slowly, only about 2 lb. per hr. being consumed, as reported in Rose's paper.

Discussion

R. F. Goudey remarked that the subject was just about three years old and was gaining a lot of headway because, as previous speakers testified, it could be made to work. Certain principles must be observed: first, mineral sulphates must be present; second, is effect of temperature, up to 65° F. there being little need for chlorination. When temperature reaches 85° F. hydrogen sulphide production is prolific. Industrial wastes may cause seasonal high demands and increase temperature. Addition of lime prior to chlorination in some cases will bring about marked economy. Use of chloramines, chlorophenols and copper sulphate may have merits. Chlorination is established but refinements to lower cost of operation may be expected.

F. S. Currie discussed chlorination experiences at the San Bernardino Imhoff-tank trickling-filter plant. Chlorine may be added at the upper end of an inverted siphon 6500 ft. from the plant, at the inlet to the plant and at the inlet to the dosing chambers. Experience has indicated most effective results are obtained by chlorinating at the upper end of the inverted siphon and at the dosing chambers. A total of 80 lb. per million gallons is added, of which 75% is applied ahead of the inverted siphon and 25% at the dosing chambers. Chlorination should be done before hydrogen sulphide has formed. Provision for storage and facilities for easy handling are important. At San Bernardino, 18 cylinders are stored horizontally and also placed horizontally on scales by use of an overhead monorail system. This

takes up considerable room. A new design at Newport Beach includes handling containers on end.

R. L. Patterson, city engineer of Newport Beach, stated that during the last year the pump operator had handled chlorination, that the property owners were satisfied and that he had not given much personal attention to it during the year. (See THIS JOURNAL, **2,** 111 (January, 1930).)

A. M. Kivari, in reply to a question by H. H. Hall, stated that prechlorination does not affect sludge digestion.

W. T. Knowlton announced that Los Angeles had just completed arrangements for testing a sewage flow of six to ten million gallons daily.

New York Symposium on Sludge Digestion and Disposal*

Sludge Digestion

By Earl F. O'Brien**

Recent advances in the science of sludge digestion, brought about through laboratory investigations, and the application of these new principles to plant operation have resulted in a flood of articles. It is well at such times to stand back a little and survey the situation as a whole. This paper will, therefore, comprise a more or less general résumé of sludge digestion, in an endeavor to bring out the fundamental principles and to contrast the conflicting views, pointing out the possibilities of reconciliation.

The first practical application of sludge digestion was the septic tank. The discovery of the beneficial effect of permitting sludge to remain under water for a time before attempting to dispose of it, was the work of no one man. The deficiences of the septic tank led to the development and use of the Imhoff tank. Contemporaneous with the Imhoff tank, but more as the result of accident than forethought, came the digestion of sludge in separate tanks. The improvement which the Imhoff tank provided by insuring better digested and less offensive sludge, resulted in its rather widespread acceptance in this country and Germany. The separate sludge-digestion tank, while perhaps known as long as the Imhoff, was not used widely until a much later date.

Investigations in the laboratories and sewage treatment plants of the United States, England, Germany and Russia have shown that the temperature of the digesting sludge and the hydrogen-ion concentration, or pH, are important factors in the success or failure of a tank to function satisfactorily. These factors affect similarly both Imhoff and separate sludge-digestion tanks. The optimum temperature, until recently, has been commonly placed at about 80° F. and the pH range between 7.2 and 7.6.

Controlled digestion implies the control of the prevailing temperature and the pH of the sludge. The solid content of sludge consists of matter which may be classified as organic and inorganic. The proportion of each depends on whether the sewerage system is separate or combined, and whether the sewage collected is strictly domestic or partly industrial.

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We are not greatly concerned with the inorganic content. It occupies space but otherwise requires little attention, unless it is of such character and amount as makes its removal in a grit chamber desirable. The heavier particles, such as sand and clay, may deposit on the bottom of the sludge-digestion tanks. This has happened in our tanks at Eastwood, N. Y., and it is proposed to install a grit chamber to prevent future trouble. Another exception may be taken in regard to sulphates in the water; these may give rise to odor trouble by splitting into hydrogen sulphide, as was proved by Clark at the Massachusetts Experimental Station. In general, however, the inorganic matter is not troublesome.

The organic matter in sewage sludge may be divided broadly into the carbonaceous and the nitrogenous portions. Organic matter, whether carbonaceous or nitrogenous, can be made stable by bacterial action in the absence of free oxygen; this is sludge digestion. The change in the carbonaceous matter brought about by bacteria is called fermentation. The change in nitrogenous material is putrefaction. Both actions are similar, and comprise primarily the breaking down of the complex combinations into more simple forms. The practical accomplishments of sludge digestion are reduction in volume, improved drainability and the absence of offensive odor during drying. Further decomposition continues after the sludge is placed on the sludge bed, but the process then becomes relatively slow and is without offense.

The action which progresses in sludge digestion is brought about through the use of the organic matter as food by the bacteria. The material is liquefied by secretions of the bacteria called enzymes, the liquid then being absorbed into the bacterial cell, where changes occur which cause the cell to grow and multiply by splitting into two parts, each part in turn becoming a new focus of life, and in turn splitting again.

The action on the carbohydrates giving rise to fermentation is assumed to be odorless. Putrefaction, or the change of nitrogenous material into simpler forms, may or may not be offensive, but it is ordinarily assumed to be offensive due to the production of hydrogen sulphide and other gases.

Advances in sludge digestion are the result of the discoveries that increased temperature and the optimum pH are extremely important in producing rapid and less offensive digestion. The maintenance of optimum temperature and pH permits bacterial life to function most efficiently. Laboratory studies of bacteria in cultures show that bacterial growth is a function of temperature. There appears to be an optimum point for each type. Up to this point growth is increasingly rapid and beyond it growth again decreases. This parallels the experience with sludge digestion.

One of the latest developments in sludge digestion is the thermophilic studies of Heukelekian and others. Dr. Rudolfs in the January, 1931,

issue of the SEWAGE WORKS JOURNAL intimates that sludge digestion may be so speeded up by temperatures around 140° F. as to permit of digestion in a matter of days rather than weeks. Other investigations, again referring to the JOURNAL, are not in accordance with this conclusion and the question is still a matter of speculation. However, it is possible that all may be correct as far as their own sludges are concerned. The effect of industrial wastes on domestic sewage is often important, some trade wastes so inhibiting digestion through toxic action on the bacteria as to make sludge digestion almost impossible.

The hydrogen-ion concentration, or pH value of the sludge, is equally as important as the temperature. Neutrality is indicated by a pH value of 7.0; values below 7.0 express acidity, above 7.0 alkalinity. A solution with a pH of 6.0, for example, is 10 times as acid as one at 7.0. The optimum pH for successful sludge digestion has been set by Rudolfs at 7.2 to 7.6 while others have found good results with either higher or lower values. Recent studies indicate that thermophilic digestion proceeds best with a pH of 7.8 to 8.2. It is quite likely that while most sludges digesting at a temperature of 80° F. will have an optimum pH value of slightly more than 7.0, it will not necessarily be the same for all sludges, particularly those having any admixtures of industrial wastes.

Fresh sludge undergoing digestion starts with an acid reaction, due to the fermentation of the carbohydrates. The reaction then becomes alkaline, the change of the nitrogenous matter being brought about slowly. The reaction will continue to be alkaline if too great an amount of fresh sludge is not added. One of the most important investigations has been the determination of the relation between the quantity of fresh sludge to be added and the quantity of alkaline sludge present. The bulletins of the New Jersey Experimental Station state that at 80° F. the amount of fresh sludge added daily may be as much as 5 per cent of the digested sludge present, on a dry basis; when the operation is not so closely watched the recommendation is from 3.5 per cent to 2 per cent. In the recent thermophilic digestion experiments, at 125° F., the amount of sludge added daily was nearly 50 per cent of the amount of volatile matter present in the ripe sludge.

The addition of lime, dolomite dust and other alkalies is practised when the reaction falls below the optimum point. The addition of too much lime may cause as serious trouble as the lack of it. The daily addition of lime with fresh solids is beneficial when the pH of the fresh solids is below 7.0. This acidity may be due to age of the sewage or through failure to introduce the settled solids promptly into the sludge digestion tank. The safest practice seems to be the addition of fresh solids to the digestion tank each day. One of the advantages claimed for the Imhoff tank is that the admission of the solids to the digestion compartment is

continuous and immediate, thereby preventing an initial and harmful acid reaction.

Experiments have been made which show that, following an initial lag in digestion due to delay in introducing fresh solids into the digestion tank, there is a period of recovery within six days. Generally speaking, however, it is accepted as better practice to secure the mixture of fresh and ripe sludge as soon as possible. In the case of thermophilic digestion it is indicated that the admission of fresh solids, for best results, must be continuous. In view of the rapidity with which the action goes on this would appear to be logical. The admission of fresh solids simply means that new food is being supplied to the bacterial population in the tank.

The addition of lime has been advocated as a regular procedure, the belief being that even when not required to correct initial acidity, it is an aid to digestion. This view is in contrast to the other, which considers the use of lime to be merely as a corrective. The correctness of either view is, I believe, not definitely proven. Certain experiments with sewage bacteria show that addition of lime within definite limits stimulates bacterial growth. Whether this holds true in sludge digestion is not always clear. When so many variables are present, as in sludge digestion, even in the laboratory, it is difficult to ascribe results to any one agent.

Digestion in the septic or the Imhoff tank is a combination of fermentation and putrefaction, each type probably predominating at certain periods. With the more common form of separate sludge digestion tank the same holds true. It is possible, however, to attempt a separation of the two types of decomposition, and this has been tried both in the laboratory and, I understand, in Birmingham, England. Theoretically, stage digestion has inviting possibilities; the carbohydrates are first permitted to undergo fermentation, and then the sludge is transferred to a second tank to permit putrefaction. Certain types of tanks, in which the sludge enters at one point and travels a considerable distance horizontally, may accomplish this. In the United States, at least, it is not yet so common a practice as the combined type.

Sludge digestion tanks take a variety of forms, depending on conditions at the site of the treatment plant and the preferences of the designer. Broadly speaking, however, they have certain fundamental differences.

The maintenance of an optimum temperature of about 80° F. is impossible in this climate without the addition of heat. The gas given off by sludge when digesting under favorable conditions is available for heating purposes. The principal constituent of the gas is methane, CH_4. The gas collected from digesting sludge is very similar to natural gas. It is derived from similar sources in each instance, namely, the decomposition of organic matter.

The manner of collecting this gas from digesting sludge is to provide some

type of roof or cover over the surface of the sludge. One type is a fixed, the other a floating cover. So far as gas collection is concerned, both accomplish the same results. The roof may also serve the purpose of submerging the scum and in this way to hinder its formation. Some tanks are provided with a domed roof, which does not submerge the scum.

The gas is usually burned in a gas-burning hot-water boiler, the water being circulated through pipe coils suspended on the interior walls of the digestion tank. Certain precautions are necessary in burning this gas due to the fact that ordinarily the supply is not constant. When a storage tank of sufficient capacity is provided, a uniform supply may be assured; storage tanks are not yet common.

The quantity of gas is usually expressed in terms of the connected population. The amount may vary from as little as 0.3 cu. ft. per capita per day to as much as 1.00 cu. ft., this latter figure holding when both activated sludge and settled sludge are digested. Ordinarily the quantity is more than sufficient to heat the tank, and in some plants it is also used as a source of power.

Computations have been made which indicate that sufficient gas is available to furnish the power required to operate an activated-sludge plant. The necessary heat for the digestion tanks would be derived from the cooling water used in the gas engines and blowers, and also from the exhaust gases. No plant as yet, to my knowledge, has attempted to do this.

Hot-water coils are probably used most frequently for heating the sludge. Other methods are—the admission of hot water directly to the tank, preheating the fresh sludge before admission to the tank, and heating and circulating the supernatant liquor. Pipe coils within the tank are perhaps the more fool-proof and apparently the only trouble to be expected is the formation of a scale due to the sludge baking on the pipes. Maintenance of a maximum temperature of 120° F. in the hot water is expected to minimize the difficulty. In designing coils for this purpose it is well to use a conservative coefficient for the heat transfer from the hot water to the tank contents.

Some engineers anticipate a considerable difference in temperature in various parts of the tank, due to the fact that transfer of heat through water is mainly by convection and convection currents in sludge were thought to be small. In the tanks at Eastwood, N. Y., differences of more than one degree Fahrenheit have not yet been found. At Salem, Ohio, a difference of 5° F. was found between the surface and the bottom of a Dorr digester.

Certain digestion tanks have been provided with an agitating device. The Dorr, Hardinge and possibly others are equipped with a stirring mechanism, consisting of radial arms driven by a motor connected to a vertical shaft. Prüss, of Essen, Germany, uses a pump which lifts the sludge and

throws it over the surface. An ingenious arrangement described by Rawn in the January, 1931, SEWAGE WORKS JOURNAL, accomplishes the same results by aid of the gas in the sludge. Other tanks, such as the Downes, provide no mixing devices except possibly a pump with piping arranged to circulate the sludge.

The advantage and necessity of mixing are argued by advocates of both theories. Data are advanced to show that increased gas production and increased concentration of solids are obtained by mixing. Sierp, of Germany, maintains, on the other hand, that the increase in gas production is mainly CO_2, of no value, and that the increased concentration is slight. Buswell, of Illinois, is an advocate of circulating only the supernatant liquor. The publication of more complete plant data will no doubt eventually prove the correctness of these theories.

The bacterial effect of mixing is, I believe, not definitely understood. Any improvement in digestion must be produced by the creation of a more favorable environment for the bacteria. They must have food and they very likely give off inhibitors or toxic liquids or gases. Whether mixing brings new food supplies to the bacteria or aids in removing a toxic substance is not entirely clear. Possibly both actions occur.

The aim of the designing engineer and the operator should be to add sludge to a digestion tank with as low water content as possible. Water occupies useful space and consumes useful heat. The more water that is wasted through the overflow, the more solids will be carried back to the settling tank. It is possible to so design and operate a plant as to reduce materially the water content of the fresh sludge. A very striking illustration of the improvement effected by careful operation is given by Fischer in describing the Salem, Ohio, activated-sludge plant. By returning the waste activated sludge to the primary settling tank and mixing it with the settled sludge, it was possible to pump sludge with an average moisture content of about 90 per cent, as compared with 98 per cent when pumping the waste activated sludge directly to the digester.

Tanks for storing digested sludge are becoming more common, the sludge being removed from the digester and stored until climatic conditions are suitable for drying. Storage tanks are likely to prove more economical in large than in small plants. They give some flexibility in operation and are, therefore, advantageous. One difficulty in the use of only one digestion unit in a plant is the trouble which will be experienced if, for any reason, it becomes necessary to empty the digester. Storage tanks would afford some relief in such a situation. In the Ithaca, N. Y., plant, where a digestion tank has just been constructed, it was possible to make use of existing septic tanks for that purpose. It had not been planned to employ these tanks for storage, but solely as relief tanks in an emergency.

Flexibility of control is always useful and with sludge digestion is im-

perative. When handling sludge certain precautions must be observed. The most common trouble is due to stoppages in pipe lines. Every effort should be made in design and operation to prevent this difficulty and remedies for overcoming stoppages should be available.

The Ithaca plant is an interesting example of the remodeling of an obsolete plant into a modern one. The plant was constructed in 1907 and consisted of a pumping station and five septic tanks. During 1928 two of the septic tanks were remodeled into sedimentation tanks, equipped with Link-Belt flight collectors. The sludge-digestion tanks and drying beds have just been completed.

Sludge is brought to the hoppers at the end of the settling tanks. It can be drawn off by gravity to a sludge sump or directly to a sludge pump in a pump well. Two sludge pumps are provided, a Barnes variable-stroke plunger pump and a Fairbanks-Morse non-clogging centrifugal pump. Ordinarily the plunger pump will be used.

The fresh sludge will be pumped through a 6-inch pipe line to the top of the digester. Digested sludge will be drawn from the bottom of the digester onto the drying beds by gravity through an 8-inch line.

Should it be desired to empty the digester the sludge can be pumped to the old septic tanks by means of either pump. In the reverse manner it can be pumped to the digester, to the drying beds or to lagoons located about 2000 feet north.

Sludge can also be put on the drying beds by gravity or by aid of the pumps. It can be circulated in the digester. All lines are laid to a grade and drain either to the pumping station or the entering sewer. Overflow liquor and drainage from the drying beds goes back to the influent to the plant and then through the settling tanks.

All sludge lines after use can be flushed with water or sewage and left that way until again used, thereby preventing caking of the sludge on the interior of the pipes. All water or sewage used in flushing returns to the settling tank or to the incoming sewer.

To sum up, it may be said that sludge digestion is a natural process of nature occurring either under controlled or uncontrolled conditions. The bacterial life, which is the active agent, is sensitive to certain factors, of which temperature and pH reaction are at present best understood. Ordinarily sludge will digest very well and quickly at about 80° F. and with pH value slightly above neutral. The presence of water combined with the solid content of sludge is a necessary evil which should be minimized as far as possible. The admission of fresh sludge promptly and uniformly will aid the bacteria in their work. Lime is a corrective for bacteria somewhat as soda is for human beings; proper feeding habits will not ordinarily require it. Its use should be watched and an over-use avoided. Separate sludge digestion is popular since temperature and reaction can be more

easily controlled. The various types of sludge-digestion tanks are practicable instruments for accomplishing results by variable methods. Time and a more complete history of their performance will enable us to judge their relative worth.

Notes on Sludge Digestion

BY WESTON GAVETT*

One of the most troublesome problems in the digestion of sludge in separate tank is the handling of the displaced liquid. When sludge is in optimum condition the liquid is quite clear, but at times, particularly when sludge is ripening, the displaced liquid may contain large quantities of suspended matter. I shall mention some instances of handling this displaced liquid at plants with which I am familiar. At the Boonton plant, constructed by Jersey City in 1924 to protect its water supply, the digestion tanks are of the suppressed-roof type, in which the water level is slightly above the bottom of the concrete roof. This prevents the scum from drying out. This suppressed-roof design was also used in digestion tanks at Briarcliff Manor and elsewhere. It is a simple and effective remedy for the scum problem and is becoming quite generally used for separate sludge-digestion tanks. The Boonton digestion tanks are lower than the bottoms of the settling tanks, consequently a settling tank may be completely emptied into the digestion tank. The operator, Mr. Mallalieu, has arranged siphon pipes in the settling tanks that decant off a large part of the supernatant liquid in the settling tanks before the sludge is removed. The tank arrangement was made possible by the location on sloping ground, with ample head available. As a considerable volume of fresh solids is discharged at one time into the digestion tanks, the displacement of the liquid in the digestion tanks by the incoming solids was a problem. This was minimized by installation of an equalizing tank, equal in size and similar to the five digestion tanks. A floating outlet pipe, with valve to regulate the flow, served as an outlet to empty this tank at a low rate, discharging the liquid drawn off to the effluent from the settling tanks, which is subsequently treated by contact beds, sand filters and chlorination. Before the solids from a settling tank are emptied into a digestion tank, the equalizing tank has been emptied and is ready to receive the displaced liquid from the digestion tank to which the fresh solids are discharged.

In activated-sludge plants at Mineola, N. Y., and Rockville Centre, N. Y., the same principle of the slow discharge of displaced liquid has been used, although worked out in a different manner. The digestion tanks are of the suppressed-roof type, with bottom of roof at the approximate water

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level in the preliminary settling tanks. The tanks are so constructed that two or three feet of gas may be collected in the tops of the tanks. The hydraulic grade line is kept constant by connection with the preliminary tanks. As the gas collects with gas valves closed, the liquid may be forced out by the formation of the gas. In practice this is done at night, and the gas is used by engines during the day shift. The liquid from the digestion tanks is thus discharged to the raw sewage at a low, uniform rate during the night when the normal load is low. In the morning, space is available in the digestion tanks for the reception of fresh solids, which may be run in by gravity, since the level in the digestion tanks has been lowered by the gas; or, if necessary, solids may be introduced by pumping.

Before gas production starts, or in case of insufficient gas production, pumping of sludge is required. For this purpose two pumps are provided, one a centrifugal sludge pump with a capacity of about 900 gal. per min. and the other a diaphragm or plunger pump of the "Mudhog" type with capacity of around 200 gal. per minute. The larger pump is used, when required, for emptying tanks and for circulating sludge when no liquid is displaced. The smaller pump is effective in pumping sludge into the digestion tanks when such pumping displaces supernatant liquid. The tank is less agitated and the displaced liquid clearer when the smaller pump is used. This combination is useful when the pump operates with a suction lift, by using the diaphragm pump to prime the centrifugal.

The matter of conservation of heat is an important consideration with reference to the quantity of solids added to the digestion tanks. When the contents of a tank have been laboriously raised to 70° F. or higher, it is a great waste of heat to displace this warm liquid by an unnecessarily large quantity of fresh solids at low temperature. At Rockville Centre, N. Y., Mr. Kneale, Superintendent of Sewers, and Mr. Anderson, Operator, have obtained good results by concentrating sludge from preliminary tanks and excess activated sludge together in a pump suction well and adding lime thereto. The liquid is returned to treatment and the concentrated solids pumped to the digestion tank. This method has the advantage of a minimum heat loss, and by decanting much of the liquid from the fresh solids the amount of liquid to be displaced from the tanks is reduced, thus decreasing the B. O. D load on the plant. The advantages of a separate sludge well for concentrating sludge, adjusting reaction and reducing head required for digestion tanks is well brought out in the excellent paper, "The Design of Sludge Digestion Tanks," by Richard Gould in the *Proceedings* of the American Society of Civil Engineers for December, 1928. The amount of heat required for heating sludge is closely related to the number and size of digestion-tank units. It is generally claimed that a few large units are desirable, there being no appreciable benefit in the use of smaller units in proportion to the growth in population. In this con-

nection the question of heating a unit larger than the population warrants deserves consideration.

In the digestion of sludge, operators seem to find that the results of Dr. Rudolfs' studies, confirmed by other investigators, work well in practice. Lime treatment to keep the pH well above 7.0° and approaching 8.0 gives good results with combined fresh and activated sludge, and raising the temperature from 70 to 80° F. accelerates digestion and gas production. Excellent digested sludge has been obtained at Mineola and Rockville Centre, from solids from preliminary settling tanks and activated sludge. At Mineola, Mr. Blansfield, the operator, obtains good results by controlling the pH with lime.

Experience in Handling Sludge at the Mamaroneck Plant

BY W. B. CORWIN*

It is rather difficult to discuss sludge digestion without referring to the other units of the plant, since one section or unit is more or less dependent upon the other. It will also be necessary to go back ten years to trace the growth and development of the handling of sludge at Mamaroneck.

The original plant was built in the summer of 1921 and served about 200 people the first year. The type of plant was plain sedimentation with chlorination of the effluent. The solids were to be cared for in what were termed hydrolyzation tanks. These were simply square compartments, with underdrained sand bottoms. The sides were open rubble walls and the top was covered with concrete. The intention was that the solids could be pumped into these compartments and the liquids would drain away, leaving the solids; in time they could be dug out and disposed of by burying. This worked fine at first but when sewer connections increased and liquid solids were pumped frequently into the hydrolyzation tanks, there was absolutely no draining of the liquids from the solids, and it soon became necessary to get rid of the sludge. The next step was to build some hopper-bottom tanks, which were to serve as digestion tanks. By this time it was realized that some form of digestion was necessary in order to dry the solids successfully on the sand beds. The hopper-bottom tanks worked a great deal better than the old ones. Digestion was fairly rapid during the months of July, August and most of September, but complaints were received due to odors from the gases and some difficulty was encountered due to foaming. Foaming was caused by the sudden warming of the sludge, which had lain dormant all winter. The gas broke through the heavy crust of scum, causing the foaming sludge to escape and

* *Mamaroneck, N. Y.*

to run all around the landscape. The other trouble was lack of storage space, consequently sludge which was not properly digested had to be put on the drying beds; there it still went through the process of digestion, instead of drying. This also caused a fly nuisance.

Our third and present installation was adopted after very careful study of our needs, as it was now understood that some form of heating was necessary to maintain steady digestion and that some form of cover was needed to keep the gases from escaping toward the houses in the near neighborhood; meanwhile the population served had reached 5000. A separate-digestion tank was built, having sixteen sides, 15 feet deep and 39 feet in diameter, equipped with a floating cover, which excluded all air from the solids placed within; the cover also has a gas dome set in a water seal. A heating coil was placed about 5 feet from the bottom and 2 feet from the side walls.

This separate-digestion unit was put in service during the late fall of 1929. At that time we had all kinds of undigested sludge in and around the plant that we could not get rid of. We put that cold, sour sludge in the digester and then began to add fresh solids daily. Tests of the condition of the sludge within the tank showed a pH value of 6, which is rather acid. A recording thermometer was placed in the approximate center of the sludge and it showed that the temperature was 63° F. We knew by this time that in separate digestion it was necessary to warm the sludge to a temperature of between 70° and 80° F., and also to maintain an alkaline condition with a pH value between 7 and 7.6. Lime was added daily to the fresh sludge placed in the digester, heat was applied in a furnace connected with the heating coil. It took all winter to bring the temperature up to 70° F. and the pH value up to 7. Gasification increased until by the middle of March outside heat was done away with and the gas from the sludge was used to maintain the desired temperature. After this no lime was needed or added until late in 1930, when a quantity of alcoholic mash was received at the plant. Since then no lime has been added, and the surplus gas has been used to heat another building containing pumps and chlorine apparatus. No trouble was experienced with clogging of the gas dome until the fall of 1930, when recirculation of sludge was tried to increase the gas yield. This caused a tendency for the partly digested material to gather near the surface of the sludge, and produced bulking of the material in the gas dome. We have now gone back to normal operation and have no further trouble with clogging.

The sludge which we now produce has a slightly tarry odor and drains very rapidly. From the middle of May to the end of October it dries sufficiently in from 10 to 14 days to be ground for fertilizer. It is eagerly sought for by gardeners, golf clubs and nursery men. We use glass-covered drying beds with forced ventilation.

We now have no trouble from odors or flies and we are gradually selling the idea to the public that our sewage plant can be made an interesting place to visit.

Sludge Disposal at Rochester

BY WILLIAM A. RYAN*

Sludge may be classified under two headings, offensive and inoffensive, which means well-digested and poorly digested sludge. The disposal of well-digested sludge is not a serious problem. It will dry readily on a well-drained drying bed and be ready for removal in two weeks or less. Poorly digested sludge is too gelatinous to dewater and may remain on the sand bed for two months without drying sufficiently to be removed.

It is therefore paramount that digestion of sludge should receive proper attention. By means of a pitcher spout pump and forty feet of one-inch hose, it is possible not only to gauge the depth of the sludge in the tank but also to collect a sample for analysis. By determining and recording the pH value, the clear water that separates in twenty-four hours, the fixed residue and the loss on ignition, the operator is in a position to know what to do to improve the digestion.

The following description and data will show what has been accomplished in the way of sludge disposal in Rochester.

There are forty sludge drying beds at the Irondequoit sewage treatment plant, each forty-four feet square. These beds consist of six inches of broken stone, eight inches of gravel, three inches of coarse sand and three inches of fine sand. The tanks are built in double units with a common sludge trough. This trough is on a wall between two rows of four beds, thereby allowing the sludge from any tank to be diverted to any one of eight beds. The troughs have a slope of one in fifty, which gives a high velocity. They are nearly self-cleansing. The underdrains are composed of three-inch farm tile which is laid with open joints on eight-foot centers. Concrete partition walls separate the individual beds, the total number being divided into four rows of ten units each. Between the first and second, and the third and fourth rows, a wide depressed channel is constructed. A narrow-gauge track is laid on the concrete floor of the channels and the tops of the heavy masonry side walls provide support for standard gauge tracks, upon which moves a gantry type crane.

When sludge is being removed, a train of four side dump cars and an electric-battery locomotive is run into either of the two channels between the drying beds. The empty car bodies are hoisted and placed on the beds by the gantry crane. When filled, the bodies are again transported to the

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train by the crane and the locomotive hauls the loaded cars to the sludge dump.

The drying season usually extends from April 15 to November 15, the best drying weather occurring during the months of June, July and August. The number of removals varies from six to ten per season, depending on the precipitation.

Some of the sludge must be lagooned when weather conditions are unsatisfactory. With the present load on the treatment plant of more than fifty million gallons of sewage per day, the sludge bed area has been reduced to less than one-quarter of a square foot per capita. It is realized today, however, that one square foot per capita is necessary with climatic conditions as they exist in the northeastern part of the United States. At Rochester, the drying time is about twelve days in summer and twenty to thirty days during the spring and fall.

The cost of sludge removal at the Irondequoit plant, under present conditions of operation, averages thirty-five cents per cubic yard. The dried sludge has a ready sale, particularly during the fall and winter months. It is hauled for distances of fifteen miles. The sludge is applied to the fairways of local golf courses and as a top dressing for lawns. Nearby fruit growers purchase a large quantity each season and state that its use increases the yield of fruit. During the winter months, truck gardeners haul the sludge and spread it on their fields. In the spring it is plowed under the surface. The gardeners claim that the sludge is an excellent fertilizer for corn, celery, cabbage and bean crops; in fact, any vegetable which grows above the ground. At this writing there is not a cubic yard of sludge available after fourteen years of operation. Appended to this article is an open letter from Mr. Thomas Maloy, City Forester of Rochester, setting forth his views and experiences in the use of sludge.

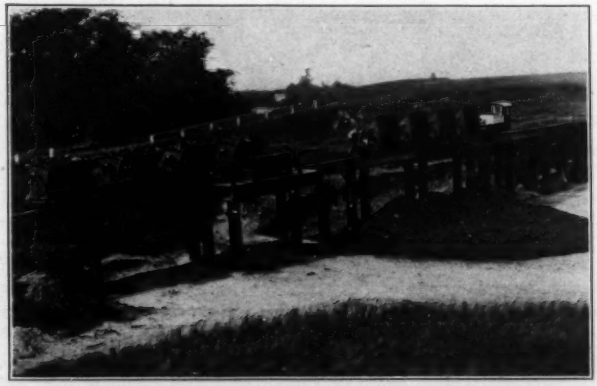
In reviewing the literature on sludge disposal, it is apparent that the subject is a vexing one. One problem for the designing engineer is whether to conserve space through the use of glass-covered sand beds or to recommend the open drying bed. The construction cost of the glass-covered beds will be greater than that of the open beds but the space required will be fifty per cent less.

For experimental purposes three pounds of ammonium sulphate was mixed with ninety-seven pounds of dry, ground Imhoff sludge. This mixture was added to alternate rows in a lawn. The results obtained were surprising. The ammonium sulphate, having readily available nitrogen, caused the grass in the fertilized rows to grow rapidly and the sludge caused the grass to assume a dark green color. It would be necessary to obtain a permit from the State Department of Agriculture and Markets in order to market such a mixture.

Imhoff or separate-digester sludge, because of its method of digestion,

is lower in nitrogen, phosphates and potash than activated sludge. Imhoff or digested sludge has mechanical value as well as chemical value. It serves a purpose in breaking up clay soil and aids in the retention of moisture in sandy soil. The grease in sludge is an objectionable ingredient. Through the addition of lime, this objection may be partially overcome. Unless sludge is built up by the addition of compounds of nitrogen, phosphorous and potassium, it will never command a high price. The main reason for encouraging the sale of sludge is to have it removed from the plant grounds. Any reasonable amount of effort to accomplish this aim is advantageous.

We have found that it was necessary to build a concrete floor over a



Trestle for Loading Dried Sludge into Trucks, Irondequoit Plant, Rochester, New York.

portion of the dump. This was accomplished inexpensively by making use of discarded paving stone from the old cobble-stone city streets. It is planned to continue the work until the entire base has been concreted. It is likewise advisable to slope the base to allow the rain water and melting snow to run off. If the dump is made convenient for the use of the farmer, he will gladly take away the sludge. It is well to charge a small price for the sludge; this revenue should more than pay for the care of the dump. Well-digested sludge does not attract flies; therefore, do not dump the screenings and the scum from the gas slots in with the sludge. This heterogeneous mixture will attract flies but will not attract the farmer.

It may be possible, provided the operator is a tactful salesman, to sell

the sludge directly from the drying beds. To accomplish this, a hard surfaced road should be built along one side of the beds and a ramp and loading platform constructed. Under no circumstances allow the truck or wagon to be driven onto the drying beds.

Sludge may be lagooned directly from the tanks to low spots on the plant grounds. This practice is not to be recommended and it is always advisable to obtain the approval of the State Department of Health, should it become necessary to dispose of the sludge in this manner.

Sludge has been lagooned at the Brighton plant for the past four years. The plant is located in a valley and there are no houses adjacent to the plant. The lagoon is a natural swamp. On the down stream side of this swamp, a six-foot stone and earth embankment has been constructed. At either end of this wall are filter boxes filled with crushed stone. The effluent has always been clear and no nuisance has been caused by this practice. There are sludge-drying beds at the plant and the sludge will be drawn onto these beds as soon as the swamp has been filled.

A portion of the sludge is lagooned at the Irondequoit plant. This is due to the overloaded condition of the tanks and lack of drying bed space.

Incineration is a possible method in extreme cases. I have had no experience with the incineration of sludge but have attempted to burn the scum from the gas slots. The scum was dumped on low land near the plant, allowed to dry for two months and then waste crank-case oil was poured over the scum. The scum burned well for two days and smoldered for four months.

An attempt was made by one chemist to recover the ash from a small amount of incinerated sludge, by washing with acid, drying and grinding the silica residue. This powder was to be used as silex in the manufacture of white paint. The process proved to be too expensive and the residue refused to become pure white.

Sludge has long been used for filling low spots. Unless sludge is mixed with dirt and seeded, or dirt is placed on top of the pile of sludge, the filled spots are unsightly.

The greenskeeper at one of the city parks states that sludge should be mixed with dirt or sand and composted for a year before spreading. The freshly removed sludge from the drying beds tends to lump and these are difficult to break up in the soil. Sludge which has been allowed to stand in a pile and subjected to frost action will become more friable and can be spread to better advantage. It might be possible to make compost piles of dry sludge in the summer and fall and sell the sludge in the early spring.

One of our customers sells a ton of sludge mixed with well-rotted manure for $5.00 for use on lawns and around flower beds. The manure is hauled to the sludge dump and mixed with the sludge as loaded.

The disposal of activated sludge is a subject with which I am not familiar. Mr. Maloy and I have experimented with Milorganite in comparison with Imhoff sludge for use on grass plots and around trees. The activated sludge proved to be somewhat quicker in its action. Large amounts of Milorganite are sold in and around Rochester.

With the introduction of the separate sludge-digestion tank, more attention must be given to the disposal of the sludge. This type of tank can be made smaller than the Imhoff tank, the sludge can be conditioned with less trouble and the tank can be heated. On account of the smaller capacity required, there will be less storage space and, therefore, more drawings per year. In many cases, the sludge will require removal during the winter months.

The village of Fairport has a separate sludge digester and their sludge is sold to one customer for $100 per year. The sludge is removed from the drying beds and piled near the beds to await removal at the convenience of the customer.

The most satisfactory arrangement of which I have any information exists at Albion, New York. A farmer comes every day during the spring, summer and fall and carts away all screenings and scum. He makes less frequent trips during the winter but there is less chance of nuisance during this season. The same customer is paid $60 per removal of sludge from the drying beds, and he may dispose of the sludge as he sees fit.

Under certain circumstances it might be possible to dry sludge to ten per cent moisture content, crush, bag and market in competition with sheep manure. By this means, it would be possible to dispose of the sludge within the city to home owners.

Conclusion

The drying and ultimate disposal of sludge is a problem that each superintendent must solve for himself. The experiences of others are an aid; but cannot always be followed to the letter.

The same attention should be given to the drying beds as to any other unit in the plant.

Clean sand should be applied to the beds to replenish what has been forked off with the sludge.

The beds should be raked over after each sludge removal.

Records of the amounts of sludge, both drawn on and removed from the drying beds, should be kept.

Do not draw too great an amount of sludge at one time; this practice may lower the efficiency of digestion within the tank and prevent the sludge from drying rapidly.

Remove the sludge from the beds as soon as it dries sufficiently to be forked. A six-tine fork is useful for this purpose.

Digest the sludge in the tank sufficiently in order that it will dry readily on the sand beds.

Dispose of the dry sludge in such a way that it will not cause nuisance.

City of Rochester—Irondequoit Sewage Treatment Plant—Sludge Data

TABLE I

Year	Cubic Yards			Moisture, %
	Wet Sludge Drawn	Drawn on Drying Beds	Lagooned	
1924	26,696	24,174	2,522	90.0
1925	25,056	22,230	2,826	90.9
1926	21,710	14,400	7,310	90.8
1927	22,935	19,584	3,351	91.9
1928	28,932	18,294	10,638	93.5
1929	26,436	24,096	2,340	92.8
1930	26,684	21,600	5,084	92.8

TABLE II

ANALYSIS OF SLUDGE DRAWN FROM TANKS

Year	Dry Basis			
	Nitrogen, %	Volatile, %	Fixed, %	Ether Soluble Matter, %
1924	1.99	44.2	55.8	9.7
1925	2.05	44.7	55.3	12.7
1926	1.99	47.2	52.8	11.4
1927	2.05	43.1	56.9	13.4
1928	2.21	48.2	51.8	12.8
1929	2.33	47.9	52.1	12.5
1930	2.33	49.6	50.4	11.6

TABLE III

DRY SLUDGE REMOVED FROM BEDS

Year	Cubic Yards	Moisture, %	Number of Removals
1924	8294	57.0	11
1925	6923	57.2	8.5
1926	5831	56.0	6
1927	7648	55.7	10
1928	5612	56.5	8
1929	6904	57.4	10
1930	6427	56.0	8

MOISTURE DETERMINATION ON SAMPLES OF SLUDGE FROM DRYING BEDS, 1930

Date	Moisture, %	Date	Moisture, %
5/5	62	7/23	55
5/8	57	8/6	48
6/4	50	9/18	57
6/13	60	10/21	58

GENERAL DATA—1930

Total sludge drawn from Imhoff tanks	26,684 cubic yards
Sludge drawn onto drying beds	21,600 cubic yards
Sludge lagooned	5084 cubic yards

Total sludge removed from drying beds	6427 cubic yards
Revenue received from the sale of sludge	$1,724.50
This represents the sale of	6898 cubic yards
In addition to this, the City Park Department obtained for which no charge was made	1088 cubic yards

Nine drawings of ten-inch depth each were drawn on the drying beds between May 7 and November 7, 1930

TABLE IV

WET SLUDGE DATA—1930

Tank No.	Moisture, %	Percentage—Dry Basis				Clear Water 24 Hours, %	pH Value	Alkalinity
		Nitrogen	Volatile	Fixed	Total Ether Soluble			
		Average Analyses						
1	93.2	2.22	49.6	50.4	12.2	50	6.55	...
2	93.6	2.42	49.8	50.2	14.6	55	6.53	456
3	92.7	2.17	49.0	51.0	13.1	50	6.55	468
4	93.6	2.39	49.3	50.7	13.4	56	6.56	419
5	93.9	2.24	49.4	50.6	12.2	53	6.52	431
6	92.5	2.13	50.2	49.8	9.7	55	6.55	462
7	92.4	2.09	50.5	49.5	10.0	48	6.60	520
8	91.8	2.35	49.6	50.4	8.5	50	6.57	460
9	92.6	2.08	49.4	50.6	11.5	55	6.62	440
10	92.2	2.25	49.4	50.6	11.1	54	6.60	439

Use of Sludge as Fertilizer

BY THOMAS P. MALOY*

The Rochester Park Bureau, during the past three years, carried out several experiments on the use of Imhoff sludge, a product of the city sewage disposal plant. The results obtained can be summarized as follows:

Imhoff sludge, in the moist state in which it is usually obtained, contains 1.1 per cent nitrogen of which 0.9 per cent is available, 0.36 per cent phosphoric acid and merely a trace of potash. There is so much moisture in it, however, that the analysis is usually given on a dry basis, as ammonia 2.5 per cent, phosphoric acid 1.0 per cent and potash 0.0. A comparison of this analysis with certain of the commercial fertilizers such as Vigoro, Loma and others, indicates that sludge is very low in all the elements that constitute a good complete fertilizer.

Ordinary horse manure has, for centuries, been considered a good fertilizer. Its chemical analysis is: available nitrogen 0.7 per cent, phosphoric acid 0.11 per cent and potash 0.45 per cent. This is not as high in fertilizing elements as we find for sludge. Pulverized sheep manure contains ammonia 1.8 per cent and of this the available nitrogen is 1.5 per cent,

* *City Forester, Rochester.*

phosphoric acid 1.25 per cent and potash 3.0 per cent. Thus it can readily be seen that sludge, despite its low content of necessary elements, actually analyzes higher than horse manure and nearly as high as dried sheep manure. Both of these latter have long been considered good fertilizers despite their low chemical analysis.

During the early part of the year 1928, the Park Bureau fertilized with sludge a considerable area in Seneca Parkway. The purpose was to discover what effect the sludge would have upon the grass already there, what effect on the trees and also whether or not the odor would be so disagreeable as to prevent its use. The sludge was applied when the ground was in a hard, frozen condition and covered with snow. The sludge was frozen and lumpy and later had to be raked and pulverized. Results were most encouraging. A very vigorous, almost rank growth of dark green grass resulted, which necessitated heavy mowing. The trees also appeared to have a healthier foliage, both in amount and color, and they also retained their foliage much longer in the fall than nearby unfertilized trees. By using sludge during the cold winter months, it was found that very little disagreeable odor resulted.

This experiment was repeated on Seneca Parkway in the year 1929 with results about the same.

Sludge was also used on some young trees about five inches in diameter which were in a very unhealthy condition. They, even more than the larger trees, showed a response to the application of sludge.

I used sludge on the grass and in the garden at my home. Results in the garden were most satisfactory. The plants were more vigorous and had a much healthier color than ever before. The whole texture of the soil was improved and made more pliable.

Before applying this fertilizer the greater part of my lawn was in a very poor condition. After application the grass came up very spotty, but whether or not it was because it was killed during the winter or whether I applied the fertilizer too heavily, I do not know. Seed was sown in an attempt to fill in the bare spots but with very little success. It seems to be very difficult for seed to germinate in a top dressing of this sludge. It was finally necessary to dig up part of the lawn entirely. New seed was sown and a fair growth of grass resulted. This difficulty occurred only in places where the grass was poor the previous year. In other places the application of sludge resulted in a very vigorous growth of grass with a rich color. Throughout the entire yard it was found that the application of sludge and the careful raking of it into the ground resulted in changing the entire texture of the soil. Where the ground was hard and compact before, it is now soft and resilient. It has a certain amount of spring to it.

The above experiments would seem to indicate that sludge can be used to a greater extent than at present, but that there is considerable that must be

learned about the proper method of handling it. It must be borne in mind that sludge has not the high fertilizing value that the commercial fertilizers possess and that its greatest value is probably from the mechanical change which its application works in the soil. It results in building up a humus content, which it is impossible to do with the commercial fertilizers.

Where it is desired to sow grass seed on places that have been fertilized with sludge, it is possible that a light application of a loam dressing over the top of the sludge might result in better germination of the seed.

It must be kept in mind also that while sludge may appear to be a very inexpensive fertilizer, actually because of its weight and water content it costs considerable to handle. This is a factor which should be taken into consideration if the sludge has to be hauled a considerable distance.

Sludge has also been found to be practically free from all weed seeds. The tomato seed is the only one that seems to retain its fertility in the sludge. This is in contrast to horse and sheep manure, both of which have a decided tendency to bring in weed seeds.

In conclusion, I believe that our experiments justify recommending sludge in preference to either horse or sheep manure. It can be recommended in all cases where the desire is to better the mechanical condition of the soil. However, in cases where it is desired merely to add to the fertilizing content and not to change the mechanical condition of the soil, at present I would suggest the use of one of the high grade commercial fertilizers in preference to sludge.

Industrial Wastes

Recovery of Proteins from Packinghouse Waste by Super-Chlorination*

By H. O. Halvorson,** A. R. Cade** and W. J. Fullen***

Sewage disposal in Austin, Minnesota, has been under development for several years. The Red Cedar River, a comparatively small stream formerly received untreated sewage from the city and packinghouse wastes from the Geo. A. Hormel Co.'s packing plant. These wastes were discharged into a quiescent pool formed by two dams placed about one and one-half miles apart. Naturally the conditions in this pool became very objectionable.

After considerable agitation the city, about six years ago, installed a treatment plant to handle the domestic sewage. At the same time the packinghouse installed screens for removal of the paunch manure and provided for primary sedimentation. The effluent from the primary clarifier was discharged directly into the river. Steps were also taken to remove stock-yard manure, which was collected and used as fertilizer on farms. These steps temporarily relieved agitation for further treatment, although they did not materially correct conditions in the river.

Even though the city installed complete treatment and the packinghouse resorted to primary sedimentation, the river was still receiving a very heavy load, more than it could possibly assimilate. The true state of affairs soon became apparent to the boards of health of Minnesota and Iowa and various civic organizations. Agitation for further treatment began, and the packing company realized that it would not be long until a more complete disposal system must be installed. The municipality and the packing company had agreed several years before that it would not be wise to mix packinghouse wastes and domestic sewage. It was therefore out of the question to improve conditions by an enlargement of the city sewage treatment plant. The packers therefore began to make studies on ways and means of handling their own waste. These studies were originally confined to their own laboratories, but for the last three years, through a coöperative agreement, they have been conducted both at Austin and at the Department of Bacteriology of the University of Minnesota.

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*** *Geo. A. Hormel & Co., Packers, Austin, Minnesota.*

Careful investigations of biological processes indicated that neither activated sludge nor the Imhoff tank and sprinkling filters had proved successful for handling this type of waste. Compound filtration, such as is used by an Iowa packer, appeared to give very good results, but this process was decided against because of the high cost of installation and operation. Biological methods were further discredited due to the fact that the treatment plant would have to be built near the packinghouse. It was felt that the odors commonly associated with the biological process would be particularly objectionable near a food manufacturing establishment.

Having ruled out biological methods, there remained only chemical precipitation as a possible means of treatment. Chemical methods are usually accompanied by high operating costs, but it was felt that if a process could be worked out which would allow the recovery of proteins, their value would lower the net cost of operation to a reasonable figure. Our chief aim, therefore, was to find ways and means of recovering the proteins from the packinghouse waste. Since the paunch and stock-yard manure, as well as the domestic sewage, are not mixed with the general packinghouse waste at the Hormel plant, it was thought feasible to make use of the recovered proteins as animal food. This use would make them more valuable than if they were to be sold as fertilizer.

Various methods of chemical precipitation have been studied in the past, but none of them have been extensively applied in this country. In this connection there are various principles that may be employed. The proteins may be precipitated by adjusting the pH to the isoelectric point, such as in the Miles Acid Process,[1] or they may be precipitated by neutralizing the charge with the salts of heavy metals, such as iron or aluminum compounds. Proteins may also be precipitated by denaturing them with oxidizing agents or other organic coagulants. The first two methods were investigated in sufficient detail to determine whether or not they were applicable to our problem. The Miles Acid Process was eliminated because good results can be obtained only in case the pH is very accurately controlled. This adjustment is too sensitive for manual control, and since no fool-proof automatic methods have been devised, it was felt that this process could not be relied upon for uniformly good results. Coagulation with aluminum and iron salts generally resulted in a precipitate having a very high ash content. In fact, the ash content in most instances was so high that the cost of filtering and drying the precipitate would absorb all profits that might be realized from the sale of the product. Ferric chloride appeared to be the most promising of the various coagulants in this class, but preliminary studies indicated that, with manual control, a sludge with a high ash content could not be prevented.

Many substances belonging to the third class of coagulants were investigated. Of these, chlorine appeared to be the most promising from the

economic standpoint. To the best of our knowledge, this chemical has not been used for this purpose in the past, although it has been known for a long time that chlorine and other halogens will precipitate proteins. This was probably first pointed out by Mulder,[2] Thenard,[3] Berzelius[4] and De-Vrij[5] as early as 1840. It was also pointed out by Rideal and Stewart[6] in 1897, in a paper in which they advocated the use of chlorine for the quantitative determination of gelatin and peptone in meat extract. Rideal[7] again calls attention to this property of chlorine in 1910. The fact that these earlier investigators pointed out that chlorine would precipitate not only proteins but gelatin and peptones as well, shows, according to our work, that they were using very high concentrations of chlorine. Although a great deal of work has been reported in the literature on the reaction of chlorine with proteins and protein products in connection with studies on chlorine antisepsis, it appears that the above references are the only ones that call attention to the precipitation of proteins by this element. To the best of our knowledge no one has attempted to make a practical application of this method of coagulating proteins. In fact, the reports in the literature would lead one to believe that the amounts of chlorine required are too excessive for any such purpose.

Theoretical Considerations

In our investigations we have found that comparatively small quantities of chlorine are required to precipitate native proteins, whereas extremely high concentrations are essential to precipitate protein split products, such as peptones. Since fresh packinghouse waste contains a comparatively large amount of native proteins, it is possible, if the waste is treated while still fresh, to precipitate a majority of the nitrogenous materials, using a range of chlorine concentration that will only coagulate native proteins. Table I shows the effect of chlorine on various types of proteins and protein split products. The concentrations given for egg albumin, fresh blood

TABLE I

EFFECT OF CHLORINE ON VARIOUS PROTEINS

Protein	Nitrogen, G. per 100 Cc.	Chlorine, G. per 100 Cc.	Cl/N Ratio	Remarks
Egg albumin	0.0096	0.0202	2.1	Break—clear
Fresh blood	0.0096	0.0240	2.5	Break—clear
Gelatin	0.0096	0.0403	4.2	Break—milky
Gelatin	0.0096	0.0500	5.1	Break—nearly precipitate
Peptone	0.0096	0.0580	6.1	No precipitation
Peptone	0.0096	0.1530	16.0	No precipitation
Tryptophane	0.0096	0.1200	12.5	Break—liquid dark
Tryptophane	0.0096	0.1075	11.2	Break—liquid dark
Glycine	0.0096	0.1920	20.0	No precipitation
Ammonium sulphate	0.0096	0.1920	20.0	No precipitation

and gelatin are the minimum amounts of chlorine required to precipitate (break) the proteins indicated. With peptone, tryptophane and glycine, the high concentrations shown in the table did not produce precipitation. Precipitation did occur with tryptophane, but this was undoubtedly an insoluble decomposition product of the amino acid. When the chlorine-nitrogen ratio is in the vicinity of 40, a nitrogenous precipitate will be obtained with peptone but not with glycine. It is to be noted from the table that when a chlorine-nitrogen ratio of from 1 to 3 is used, only native proteins are precipitated. Gelatin is precipitated with a ratio of around 5, whereas peptone forms no precipitate, even with a ratio of 16. The same holds true for the amino acids.

It is conceivable that, in a mixture of proteins and their decomposition products, the latter will react with the chlorine before it has a chance to coagulate the native proteins. Thus, in mixtures of this kind, larger quantities of chlorine would be needed to precipitate the latter. Various mixtures of the substances indicated in Table I were investigated with the results as given in Table II.

TABLE II

THE EFFECT OF CHLORINE ON MIXTURES OF PROTEINS AND THEIR DECOMPOSITION PRODUCTS

Protein	Nitrogen, G. per 100 Cc.	Protein	Nitrogen, G. per 100 Cc.	Chlorine, G. per 100 Cc.	Cl/N Ratio
Albumin	0.0074	Tryptophane	0.0000	0.0145	2.0
Albumin	0.0070	Tryptophane	0.0005	0.0240	3.2
Albumin	0.0059	Tryptophane	0.0020	0.0476	6.0
Albumin	0.0037	Tryptophane	0.0048	0.0817	9.6
Albumin	0.0070	Glycine	0.0005	0.0215	2.8
Albumin	0.0037	Glycine	0.0048	0.0560	6.6
Albumin	0.0070	Peptone	0.0005	0.0215	2.8
Albumin	0.0037	Peptone	0.0048	0.0301	3.5
Albumin	0.0055	Gelatin	0.0024	0.0173	2.2
Albumin	0.0037	Gelatin	0.0048	0.0173	2.1
Gelatin	0.0048	Blood	0.0120	0.0522	3.2
Gelatin	0.0024	Blood	0.0180	0.0522	2.5

In each case the quantity of chlorine given is the minimum required to produce a precipitate. It is to be noted that in the presence of decomposition products, a higher ratio of chlorine to nitrogen is required than is necessary in pure solutions of native proteins. Amino acids appear to increase this ratio more than peptones, and peptones in turn more than gelatin. It is to be kept in mind, however, that in determining this chlorine-nitrogen ratio, the nitrogen figure used is the total nitrogen calculated from both the decomposition products and the proteins, so that in the presence of nitrogen compounds which are not precipitated, a certain amount of chlorine must be added to satisfy their demand in order to bring

about coagulation. In the case of mixtures of protein and gelatin, however, it appears that the gelatin as well as the native protein is removed. This has been verified both by nitrogen analysis and by the fact that the filtrate obtained would give no further precipitate when treated with large excesses of chlorine. Figure 1, which illustrates this point, shows three beakers; the first, *A*, containing egg albumin solution, the last, *C*, containing gelatin solution, and the second, *B*, containing equal parts of the same albumin and gelatin solutions. Each solution contains the same total nitrogen content. In *A* the chlorine coagulated the albumin leaving a clear supernatant liquid, while in *C*, although the gelatin is rendered insoluble, the solution above is quite milky. However, when enough native protein is present in a mixture containing gelatin, the former, in precipitat-

FIG. 1.—The Effect of Chlorine on Egg Albumin and Gelatin Solutions.

ing, will absorb and carry down with it the fine suspended particles of the latter, thereby leaving a practically clear supernatant liquid as shown in *B*.

In coagulating proteins with chlorine, definite ranges of chlorine concentration are required before any precipitate is formed. It has been observed that a small amount of chlorine does not produce a small amount of precipitate, with more precipitate produced when more chlorine is added. Instead, all the proteins precipitate when a definite range is reached. This is observed in Table III, in which egg albumin solution is used in two concentrations.

We have found that the concentration of chlorine required to precipitate the proteins is dependent upon the pH of the solution. In fact, when the

reaction is adjusted to a final pH of approximately 4, precipitation can be effected with a minimum amount of chlorine. When the protein solutions are made up in distilled water having no buffering alkalinity, it is found that the hydrochloric acid produced in the reaction brings the pH to a point somewhere between 2 and 3. To get optimum results, therefore, in a solution of this type, it is necessary to add some alkali to bring the pH back to 4. When the protein solutions are made up with well water or water containing considerable residual alkalinity, there may be present more than enough basic constituents to combine with the excess hydrochloric acid, making it necessary to add acid to maintain the optimum pH.

TABLE III

THE EFFECT OF VARYING THE CHLORINE CONCENTRATION ON ALBUMIN SOLUTIONS

Nitrogen, G. per 100 Cc.	Chlorine, G. per 100 Cc.	Cl/N Ratio	Remarks
0.0074	0.015	2.0	No precipitation
0.0074	0.016	2.1	Precipitation just beginning
0.0074	0.017	2.3	Complete precipitation
0.0740	0.145	1.9	No precipitation
0.0740	0.160	2.1	Precipitation just beginning
0.0740	0.170	2.3	Complete precipitation

Likewise, with samples of wastes obtained from the various packing industries, it was found necessary to add acid for the same reason. Another optimum point of precipitation occurs with egg albumin when the solution is adjusted to a pH somewhere below 2. Thus we find that with this particular protein, the chlorine can also be conserved by adding a large quantity of acid. We do not know whether this same phenomenon holds true for all types of proteins found in packinghouse wastes, but in view of the fact that the quantity of acid required to bring the reaction to this pH is excessive, this feature has not been investigated. Typical results obtained are to be found in Table IV.

TABLE IV

THE EFFECT OF pH ON PRECIPITATION OF EGG ALBUMIN WITH CHLORINE

Albumin, G. per 100 Cc.	Chlorine, G. per 100 Cc.	Cl/N Ratio	Remarks
0.0074 + 1 cc. $N/10$ H_2SO_4	0.0083	1.12	No precipitation
0.0074 + 6 cc. $N/10$ H_2SO_4	0.0083	1.12	No precipitation
0.0074 + 10 cc. $N/10$ H_2SO_4	0.0083	1.12	Precipitate formed in $^1/_2$ hour
0.0074 + 15 cc. $N/10$ H_2SO_4	0.0083	1.12	Precipitates
0.0074 + 1 cc. $N/10$ NaOH	0.0083	1.12	Precipitates
0.0074 + 3 cc. $N/10$ NaOH	0.0083	1.12	Precipitate formed and redissolved

It is to be observed from this table that egg albumin is precipitated, with a chlorine-nitrogen ratio of slightly more than 1.0, when 15 cc. of $N/10$ sulphuric acid or when 1 cc. of $N/10$ sodium hydroxide are added to egg albumin solutions containing 74 parts per million of nitrogen. In these

solutions, the respective pH values are approximately 2 and 4.2. When 3 cc. of sodium hydroxide are added, the precipitate first forms, but redissolves when the reaction reaches a pH above 4.2. The protein is not permanently altered because it has been found that by readjusting the reaction to a pH of 4.2 or less, the precipitate reforms. This reversible precipitation cannot be produced unless a certain minimum amount of chlorine is added.

That a similar saving of chlorine can be effected in the case of other proteins is indicated in Table V.

TABLE V

THE EFFECT OF pH ON THE PRECIPITATION OF VARIOUS PROTEINS WITH CHLORINE

Protein	Nitrogen, G. per 100 Cc.	Alkali	Chlorine, G. per 100 Cc.	Cl/N Ratio
Albumin	0.0096	O	0.0210	2.1
Albumin	0.0096	CaO	0.0130	1.3
Gelatin	0.0096	O	0.0420	4.2
Gelatin	0.0096	CaO	0.0210	2.1
50–50 mixture albumin and gelatin	0.0096	O	0.0260	2.6
50–50 mixture albumin and gelatin	0.0096	CaO	0.0150	1.5
50–50 mixture gelatin and blood	0.0096	O	0.0310	3.2
50–50 mixture gelatin and blood	0.0096	CaO	0.0100	1.0
50–50 mixture albumin and peptone	0.0096	O	0.0240	2.5
50–50 mixture albumin and peptone	0.0096	CaO	0.0125	1.3
50–50 mixture blood and albumin	0.0096	O	0.0280	2.8
50–50 mixture blood and albumin	0.0096	NaOH	0.0110	1.1
50–50 mixture blood and albumin	0.0096	CaO	0.0110	1.1
Blood	0.0096	NaOH	0.0105	1.1
Blood	0.0096	O	0.0270	2.8
1–3 each albumin, blood and peptone	0.0096	O	0.0480	5.0
1–3 each albumin, blood and peptone	0.0096	CaO	0.0270	2.7

The concentrations of chlorine shown in Table V are just sufficient to produce precipitation. It is to be observed from this table that a considerable saving of chlorine can be effected with all of the various proteins tested if the pH is properly adjusted. The quantity of alkali needed depends upon the amount of chlorine used. Since that in turn depends upon the concentration of the proteins, the quantity of alkali added must be in proportion to the amount of proteins present. Thus we find that in a solution containing 100 parts per million nitrogen, 1.4 cc. of $N/10$ sodium hydroxide is required, whereas a solution containing 250 parts per million of protein nitrogen requires 3.7 cc. of sodium hydroxide solution. We have also found that it does not make any difference which alkali is used, as long as the final pH reaches a point slightly less than 4.2.

The question may be raised as to whether the precipitate obtained with a combination of chlorine and alkali is different from that obtained when chlorine alone is used. In fact, it has been suggested that if the chlorine

were eliminated entirely, a precipitate could be obtained by an adjustment of pH alone. This has been carefully tested on protein solutions as well as on packinghouse waste samples, and we have found that in all cases a certain minimum amount of coagulant is essential for the production of a precipitate with a clear supernatant liquid. In certain sewage samples, some precipitation can be produced by pH adjustment alone, but the supernatant liquor is not clear.

We have observed that when chlorine reacts with decomposition products such as amino acids and peptones, secondary reactions occur in which carbon dioxide is evolved. That such reactions take place has been pointed out in the literature, notably by Dakin[8] and Wright.[9] Liberation of gases in the secondary reaction sometimes causes the precipitate which has

FIG. 2.—The Effect of Chlorine on Solutions Containing Varying Amounts of Egg Albumin and Peptone.

settled to the bottom to rise to the surface, as illustrated in Figure 2. The four beakers each contained mixtures of albumin and peptone of the same total nitrogen content. No. 1 contained albumin alone; No. 2, 75 per cent albumin and 25 per cent peptone; No. 3, a 50 per cent mixture of each; and No. 4, 25 per cent albumin and 75 per cent peptone. Thus it is seen that side reactions, caused by the increased amount of protein decomposition products, produce gases which cause a part of the precipitate to rise to the top of the liquid.

A similar phenomenon will take place if carbonates are present in the original solution. In fact, if carbonates are present, gases will form immediately, so that a part of the coagulated proteins will rise to the surface at once instead of first settling to the bottom. In Figure 3 a series of beak-

ers is shown, the first three of which (5, 6, 7) contained 50–50 mixtures of albumin and peptone, the same as were present in beaker (3) of Figure 2, in which case floating occurred. Beaker 8 contained albumin only, the same as beaker (1) of Figure 2, in which no floating occurred. These solutions had been adjusted to the optimum pH by various alkalies such as lime (5), ammonium hydroxide (6) and sodium carbonate (7, 8). It can be seen that in those solutions containing carbonates, the coagulum has risen to the surface and floats, whereas in solutions adjusted by other alkalies, the floating which occurred without the alkali adjustment was prevented. A similar experiment in which caustic soda was used gave results exactly like those with lime (5).

In treating samples of wastes from various packing plants, we have found

FIG. 3.—The Effect of Various Alkalies on the Formation of Floating Sludge.

that there are always sufficient quantities of protein decomposition products to bring about this phenomenon. This complicates the practical application somewhat, but the difficulty can be overcome by properly stirring the mixture for a period of time so as to liberate the gases which are formed. A gentle stirring for a period of 20 minutes is generally sufficient to allow the precipitate to settle and remain at the bottom. This agitation is also desirable for other reasons, since it has been found that the precipitates formed from some of the proteins, such as gelatin, are fine and settle with difficulty, whereas those produced from the native proteins are very flocculent. By proper agitation, the flocculent precipitate occludes the fine precipitate, and it is thus possible to get a clear supernatant liquid, even though finely divided solids are present.

It may also be of interest to discuss the fate of the chlorine. When the minimum amount of chlorine required to precipitate the proteins is used, approximately 65 per cent of that added can no longer be accounted for by thiosulphate titration, indicating that this portion of the added chlorine has reacted as an oxidizing agent for the formation of stable chlorine compounds in which the chlorine is no longer available. When pure protein solutions are treated, practically all the available chlorine remains in the precipitate, with little, if any, present in the filtrate. In solutions containing mixtures of precipitable proteins and non-precipitable decomposition products, the available chlorine in the filtrate bears a direct relationship to the amount of nitrogen present in the filtrate. Of course, if large excesses of the chemical are added, these relationships do not hold. In the latter cases, a larger percentage can be accounted for as available chlorine, and more of it can be found in the supernatant liquid. A more detailed consideration of the fate of the chlorine will be published elsewhere. It is of interest to note, however, that the available chlorine in the effluent is directly proportional to the amount of nitrogen that is not precipitated. This excess chlorine will therefore be in proportion to the amount required to partially stabilize the compounds and to reduce the B. O. D.

Plant Operation

The above theoretical studies throw some light upon the practical results that can be obtained. They clearly show that efficient results can be secured only when the waste contains a comparatively large amount of native proteins, and when it is treated before septic action sets in, so as to prevent the formation of decomposition products that do not precipitate.

TABLE VI

DATA ON PLANT OPERATION

Substance	Raw Sewage (Parts per Million)	Effluent (Parts per Million)	Percentage Reduction
Organic nitrogen	166.8	44.0	73.0
Ammonia nitrogen	17.3	14.4	..
Total nitrogen	184.1	58.4	68.0
Total solids	4971	3235	35.0
Fixed solids	2431	2582	..
Volatile solids	2540	652	74.4
Sodium chloride	2422	2292	..

10,591 pounds of sludge obtained from 660,000 gallons.

The efficiency of the process in any particular application will therefore depend upon the relative amounts of native proteins present. Work done at the Hormel packing plant showed that in various samples of sewage, from 40 to 85 per cent of the total organic nitrogen could be removed by chlorine precipitation, the percentage removal depending largely upon

the source of the sample. Samples containing relatively high percentages of blood gave the higher results, whereas those that had become septic or otherwise contained large amounts of peptone or gelatin gave lower yields. Composite samples from typical runs usually showed removals of from 60 to 89 per cent. The following table gives some representative results of actual plant operation.

The data reported in the above table are representative of results obtained from carefully composited samples on days when the packing plant was operating at normal capacity. The significant figures are those showing reduction in organic nitrogen and volatile solids, the former being 73 and the latter 74 per cent. In the various analyses that have been made, these figures show a variation of from 60 to 80 per cent.

When the plant is operating at normal capacity, about 5 tons of sludge are obtained daily. About two tons of the sludge come from the primary clarifier, and three tons from the secondary clarifier. The following is a typical analysis of the chlorine precipitated sludge when dried:

Moisture	3.70%
Protein	48.90
Ammonia	9.50
Fat	22.72
Ash	11.60

The sludge from the primary clarifier is lower in organic nitrogen and higher in ash, while its ammonia content is generally below 8.5 and above 6.0 per cent. The raw sewage has a B. O. D. of from 1800 to 2400. The treatment shows a reduction in B. O. D. which parallels very closely the reduction in volatile solids or organic nitrogen. With proper control, a reduction of from 80 to 85 per cent can be obtained.

Figure 4 shows the plant, and Figure 5 is a diagrammatic sketch of its various parts. As shown in this sketch, the raw waste first enters the primary clarifier after going through a small grit chamber. The effluent from this clarifier enters the first mixing chamber, where chlorine is introduced by means of Duriron ejectors. The treated waste then passes through the second mixing chamber and into the secondary clarifier, from which the effluent is discharged directly into the river.

A small amount of sludge rises to the surface of the secondary clarifier. This is removed by a Dorr skimmer and returned to the influent of the first mixing chamber. The additional mixing it receives on passing through the mixing chambers a second time releases the gas, which caused it to float, so that it settles on reëntering the clarifier.

Both clarifiers are provided with Dorr thickeners and Dorr diaphragm pumps for the removal of the sludge. The primary sludge, being putrescible, must be filtered and dried quickly to prevent septic action. This can be easily done by means of suction filters and rotary driers. The sec-

ondary sludge, being sterile and containing residual chlorine, can be dried on a sand bed. It can also be dewatered by a Dorr suction filter and a rotary drier.

More detailed descriptions of the plant may be found in *The National Provisioner* for February 14, 1931, and in *Municipal Sanitation* for April, 1931.

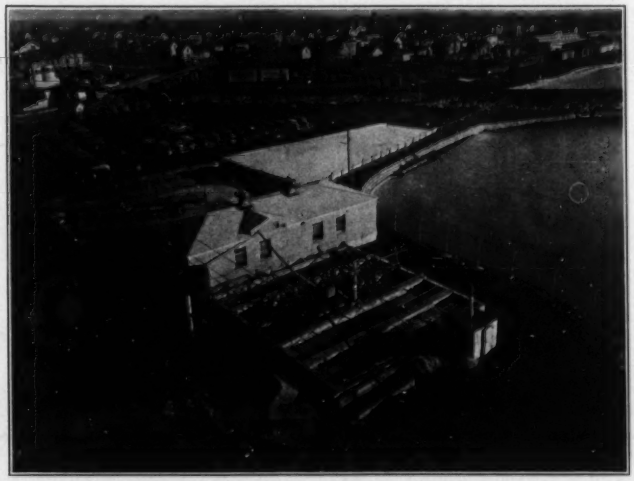

FIG. 4.—The Hormel Disposal Plant for Treating Packinghouse Waste.

The following shows the cost of operation of the treatment plant:

	Per Day
Three men on clarifier	$16.00
Power	
28 hp. for clarifiers, mixers, etc., at 60 per cent rating	4.50
Chlorine	
1500 lb. per day at 2.3¢ per lb.	34.50
Interest, depreciation and upkeep on $50,000 at 12 per cent	20.00
	75.00

There will be additional costs involved in the handling of the sludge. These were not included because further work must be done before we know its ultimate disposition, upon which the method of handling will depend to

a certain extent. In any case, the nitrogen value of the sludge will be more than enough to defray this handling cost.

Feeding experiments have been conducted with both primary and secondary sludge. Results indicate that the primary sludge can be used in low grade tankage for hog food. The secondary sludge has proven toxic when fed to rats, but this toxicity can be overcome by extracting the the fats. It appears that in the drying of the sludge, the available chlorine attached to the proteins combines with the fat in such a way as to make it toxic. Further work will have to be done before we can determine whether it will be more economical to extract the fat and use the material for feeding purposes, or to prepare the material as it is for fertilizer. If the material can be made fit for animal food, the income from the sale of the sludge should be sufficient to pay not only the cost of handling but also all other operating expenses. It is believed that there is sufficient fat

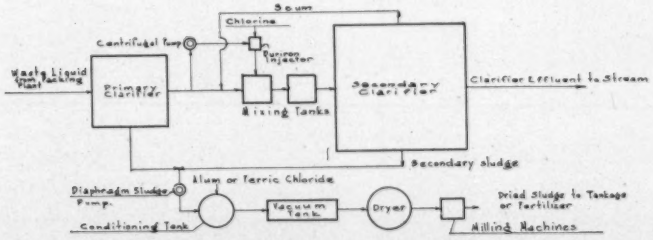

FIG. 5.—Diagrammatic Layout of the Waste Treatment Plant, George A. Hormel & Co., Austin, Minn.

present in the sludge to defray any expenses involved in its extraction. The above analysis shows that the fat content is approximately 23 per cent, which means that about one ton of fat can be obtained from 5 tons of sludge.

It is to be noted from the above experimental work that a saving of chlorine can be effected with a proper control of pH. Since the average waste encountered in the packing industry contains more than enough alkali to neutralize the hydrochloric acid, pH adjustment involves the addition of some inexpensive acid. With automatic control of pH and chlorine dosage, it should be possible to cut the chlorine consumption in this particular plant to less than 1200 lb. per day.

A fair idea of the efficiency of the process is indicated by the improvements effected in the river. Previous to the institution of this treatment the pool in the Cedar River in Austin was in an extremely bad condition. A large amount of sludge floated on the surface and the odors of hydrogen sul-

phide and mercaptans were prevalent throughout the town. No fish had been observed in the river either in the area between the two dams or a few miles below the dam. Three weeks after treatment had been started the odors disappeared, and within three months no more sludge could be seen on the surface of the pool. At the present time, after approximately 8 months of operation, the water is remarkably clear, and the bottom can be seen in places where the depth does not exceed four or five feet. Many fish have been seen this spring just below the lower dam, and a few have been observed in the pool between the two dams. Residents in the city maintain that the river is now in a better condition than it has been for the past twenty years.

The chief advantages of the chlorine process appear to be:

1. Ease of control.
2. Dependability.
3. Reduction in B. O. D. greater than that obtained by a mere removal of the nitrogenous compounds.
4. Production of an effluent containing available chlorine which tends to stabilize and delay decomposition of organic material present.
5. Recovery of a residue with a low ash content.
6. Production of a stable sludge which can be dried on sand beds without danger of septic decomposition.

There are certain disadvantages which should be mentioned:

1. Toxicity of recovered material for animals, unless fats are extracted.
2. Floating of coagulum due to the side reactions which produce gas. This latter disadvantage may be overcome by suitable agitation.

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Editorial

Sludge Inoculation and Concentration

It has been shown conclusively by research here and abroad that satisfactory digestion of sewage sludge depends, in large measure, upon the mixture of proper quantities of fresh solids and ripe sludge. Appreciation of this fact was reported nearly 20 years ago by those two outstanding proponents of sludge digestion, Imhoff in Germany and O'Shaughnessy in England. Dr. Imhoff took out a patent in 1912 (D. R. P. 275498) covering the procedure of mixing fresh solids and ripe sludge prior to digestion. This mixing was intended to accomplish in separate digestion what is accomplished automatically, to some extent, in Imhoff tanks, because of the slow and uniform deposition of fresh solids on the surface of more or less ripe sludge, with mixing effected by gas ebullition. In an effort to improve this mixing effect, Stevenson in 1913 used an air lift for pumping ripe sludge from the bottom of the Philadelphia Imhoff tanks (Pennypack Creek) and discharging it at the surface, through the gas vents.

During the next ten years, apparently little use was made of these developments. Not many separate-digestion plants were built in Germany and the United States, but in England O'Shaughnessy at Birmingham had on his hands the problem of disposing of the sludge from nearly one million people, by separate digestion. In 1911, following extensive laboratory work, he put into operation the procedure in digestion of sludge which is still in operation. He has summarized his twenty-five years of experience in THIS JOURNAL, January, 1931, pages 86 to 95. He states: "At Birmingham, mixing has been done as follows: A small quota of ripe sludge is delivered into the pump in order to eliminate sterile pockets in the crude material. The mass thus seeded is delivered quietly into a much greater mass of fermenting sludge in the digestion chamber."

In 1921, Dr. Imhoff installed a secondary sludge-digestion tank at Essen-Frohnhausen to augment the capacity of the Imhoff tank, built in 1909. The new installation was so arranged that ripe sludge could be drawn from the bottom of the separate-digestion tank and mixed with the partially digested sludge from the Imhoff tank. The mixed, seeded sludge was pumped to the top of the separate-digestion tank.

In 1925, Dr. Prüss patented his scheme for circulation of sludge (D. R. P. 441851). A circulating pump was installed in a separate-digestion tank of a new type at Essen-Frohnhausen. The Prüss recirculation scheme is so well known as to require no detailed description. (See THIS JOURNAL,

October, 1930, pages 477 to 485.) Dr. Prüss goes further than other investigators who recommend only seeding of the incoming fresh solids, in that he recommends daily circulation or overturning of the entire contents of the tank. He states that "we do not agree with the common practice of mixing the daily addition of fresh sludge only once with about the same quantity of well-digested sludge in order to prevent acid digestion."

Mr. O'Shaughnessy and Dr. Imhoff object to Dr. Prüss' daily overturning since it appears to dilute the average contents of the tank to 95 per cent or more moisture, and may cause short-circuiting of undigested solids.

As a result of these earlier developments, many of the recently installed separate-digestion tanks in the United States have been provided with pumps for recirculation of sludge, or for mixing ripe sludge with the incoming fresh solids. Sufficient operating experience is not yet available to determine the advantages or disadvantages of such seeding or recirculation. All experience points to the desirability of at least seeding the fresh solids.

The close analogy with the practice of returning activated sludge to the influent of the aeration tanks in the activated-sludge process is apparent. But why not carry the analogy further? Fill-and-draw operation of the activated-sludge process was abandoned long ago for the continuous-flow procedure. Why not operate separate sludge-digestion tanks with a continuous inflow of fresh solids seeded with the proper proportion of returned ripe sludge? This might be impracticable in small plants with no supervision at night, but should be feasible in large, well-operated plants. The slow, continuous rate of feeding solids would conform more closely to the procedure in Imhoff tanks, the advantage of which is undeniable.

The successful development of thermophilic digestion would make such continuous feeding of seeded sludge even more advantageous. If digestion time could be cut down to 5 or 10 days the return of ripe sludge would help to provide the uniform, continuous seeding that seems to be desirable for rapid digestion.

Another marked improvement in digestion of sludge would be available if fresh solids could be so concentrated before entering the digestion tank that it would be unnecessary to draw off supernatant liquor. The disposal of this liquor is always a problem, particularly at activated-sludge plants where the return of the supernatant liquor to the aeration tanks has interfered more or less with the successful operation of the process. Probably much of the difficulty has been due to introduction of supernatant liquor at too high a rate, over a short period, but it is undoubtedly desirable to reduce the volume of supernatant liquor as much as possible by preliminary concentration of incoming solids. Progress in this direction has been made by the introduction of excess activated sludge into the influent to the primary-settling tank, as at Salem, Ohio (THIS JOURNAL, January, 1931, pages

30 to 37). The moisture of the combined sludge, as withdrawn to the digestion tanks, should be 95 per cent or lower. If this settled sludge could be reduced to 90 per cent or lower by a centrifuge, filter or other mechanical device, it might be possible to do away with the displacement of supernatant liquor, or at least to reduce it to a negligible volume.

The acceleration of sludge digestion and removal of most of its difficulties might be accomplished by the following procedure, subject to the modifying effect of detailed investigation:

(1) Concentrate fresh and activated solids to 95 per cent moisture, by settling.

(2) Concentrate the settled sludge to 90 per cent or less, by mechanical devices.

(3) Introduce concentrated solids, mixed with the optimum amount of returned ripe sludge, into a digestion tank heated to 125° F., with slow mixing of the contents.

(4) Withdraw sludge, including supernatant liquor.

Disposal of digested sludge is another problem, but in order to complete this paper layout we might add mechanical concentration of digested sludge by centrifuges or filters, and disposal of the 60 per cent sludge on the sludge dump, or by incineration, or by fertilizer manufacture.

In the sewage-plant Utopia these procedures may work smoothly, cheaply and as a great improvement over our present practice.

Proceedings of Local Associations

New England Sewage Works Association
Third Annual Meeting

Hartford, Connecticut

April 27, 1931

The Third Annual Meeting of the New England Sewage Works Association was held at the Hotel Bond, Hartford, Conn., on April 27, 1931. The meeting was unusually well attended, there being 103 members and guests registered and several guests who attended the morning session but did not register.

For the first time the Association invited manufacturers of sewage treatment plant equipment to present exhibits of their products. These exhibits were held in a room adjoining the meeting room and being open throughout the day and evening permitted ample opportunity for those attending the meetings to inspect the exhibits and talk with those in charge. These exhibits proved a very interesting and valuable part of the program. Exhibits were presented by the following manufacturers:

Wallace & Tiernan
Paradon Company
Link-Belt Company
Pacific Flush Tank Co.
Inertol Company
Eimer & Amend
Dorr Company
Hume Pipe Company
Weston Gaskets

The morning session opened at 10:30 A.M. Due to business engagements President Coburn was unable to attend the meeting. Vice-President Warren J. Scott presided at all sessions.

The first paper at the morning session, "Sewage Chlorination," was presented by Mr. L. H. Enslow, of the Chlorine Institute of New York.

The second paper, "Sewage Plant Laboratory Tests," with demonstrations, was given by Mr. Roy S. Lanphear, Worcester Sewer Dept., and Mr. Caryl C. Carson, Conn. State Dept. of Health, Hartford.

Mr. R. S. Rankin, The Dorr Co., presented the third paper of the morning session entitled, "Settling Tanks."

The fourth paper, "The Development of Sewage and Waste Treatment

at South Manchester, Conn.," presented by Mr. L. H. Geer, of the South Manchester Sanitary District, described the plant to be inspected in the afternoon.

Owing to lack of time it was unfortunately necessary to omit most of the discussion of these papers. Following the presentation of the papers the Vice-President opened the business session.

The report of the Treasurer showing a balance of $151.59 was read and accepted.

The report of the Secretary showing a membership of 99 was also read and accepted.

There being no unfinished business or committee reports, the matter of new business was taken up. The first item under this head was consideration of the proposed amendments to the Constitution, preliminary notice of which had been sent to all members 30 days preceding the meeting. It was voted to amend Article VI to read: "The officers of the Association shall be a President, a Vice-President, and a Secretary-Treasurer, and two Directors. The term of office shall be one year. Officers shall be elected at the Annual Meeting. No officer, except the Secretary-Treasurer, shall serve more than two consecutive years."

It was voted to amend Article VII to read: "The President, Vice-President, Secretary-Treasurer and the Directors shall constitute the Executive Committee to carry on the work of the Association between Annual Meetings.

It was voted to amend Article X to read: "The officers are hereby authorized to join this Association with other Associations constituted for like purposes in forming a Federation Board for the publication of a Journal of the Federation of Sewage Works Associations. The Directors of this Association shall be the representatives on said Federation Board in accordance with its articles of organization. The officers are authorized to pay to said Federation Board the entrance fee and the annual fee required per capita as collected from each member of this Association for the publication, as in accordance with the said articles of organization, but not to exceed one dollar ($1.00) annually. If said requirements are carried out, each member of this Association in good standing shall receive a copy of the publication issued by the Board."

The Chair appointed as a nominating committee to submit a list of officers for the coming year with instructions to report at the close of the business meeting, Messrs. Suttie, Wright and Kennedy.

On the suggestion of the Executive Committee it was voted to appoint a committee to consider the subject of sewage sampling with Mr. R. S. Lanphear of Worcester as Chairman, the other members to be appointed by the Ex-Committee after consultation with Mr. Lanphear.

The nominating committee presented its report, nominating the follow-

ing candidates for the various offices: *President*, Warren J. Scott, Hartford, Conn.; *Vice-President*, Roy S. Lanphear, Worcester, Mass.; *Secretary-Treasurer*, F. Wellington Gilcreas, Boston, Mass.; *Directors*, Stuart E. Coburn, Boston, Mass., Julius W. Bugbee, Providence, R. I.

It was voted that the Secretary cast one ballot for the election of these candidates. This was done and the officers were declared elected.

It was voted to extend the thanks of the Association to Mr. Stuart E. Coburn, the retiring President, for his efforts in making the Association and its meetings a success. The Secretary was instructed to telegraph Mr. Coburn to this effect, expressing the regret of the Association at his unavoidable absence from the meeting. There being no further business the meeting adjourned for luncheon held at the Hotel Bond.

Following luncheon, automobiles left the Hotel Bond for South Manchester to permit those attending the meeting to inspect the construction and operation of the South Manchester Sewage Treatment Plant. This proved a most interesting inspection of a novel method of sewage treatment.

Upon returning to Hartford many availed themselves of the opportunity to visit the laboratories of the Conn. State Department of Health.

The annual dinner of the Association was held at the Hotel Bond at 6:30 P.M. Following the dinner a Round Table Discussion on the following subjects was held:

1. "Effect of Industrial Wastes on Sewage Treatment."
2. "Sludge Pumping."
3. "Fertilizing Value of Sludge."
4. "Paints to Preserve Concrete and Metal Surfaces."

The meeting adjourned at 9:30 P.M.

F. Wellington Gilcreas, *Secretary*

Oklahoma Water and Sewage Short Course Seventh Annual Meeting

Stillwater, Oklahoma

April 19–25, 1931

Under the auspices of the Oklahoma Water Works Conference, the Oklahoma A. and M. College, the Oklahoma State Board of Health and the Oklahoma Department of Vocational Education, the Seventh Short Course was held at the Oklahoma A. and M. College, Old Central Building, Stillwater, Oklahoma, April 19–25, 1931.

After a two-day inspection trip of water and sewage plants in nearby towns, the program began. About two days were devoted to water treatment and most of the papers concerning sewage were presented on April 23.

Ludwig Schmidt of the Bureau of Mines, Bartlesville, took up "The Disposal of Oil Field Wastes."

"Aer-O-Mix—An Effective Aerator and Intimate Mixer" was explained by Herman B. Anderson of Vogt Brothers Mfg., Co., Louisville, Kentucky.

The sewage treatment plants at Enid, Tulsa and Weatherford, Oklahoma, were described, respectively, by Messrs. E. R. Diehl, formerly Asst. Engineer of the City Engineering Department of Enid, F. M. Veatch of Black & Veatch, Consulting Engineers, Kansas City, Missouri, and L. M. Bush, Consulting Engineer, V. V. Long and Co., Oklahoma City. Slides were shown of the sewage treatment works of the Sanitary District of Chicago, furnished by F. W. Mohlman.

"Recent Trends in Sewage Treatment Methods" were taken up by Ernest Boyce, Director and Chief Engineer of the Kansas State Board of Health, Lawrence, Kansas.

A paper on "The Utilization of Sewage Sludge" was presented by H. J. Harper, Professor of Soils, Oklahoma A. and M. College, followed by a discussion by A. D. Bull, City Chemist, Lawton, and L. H. Scott, Filtration Engineer, Oklahoma City.

Mr. C. R. Sandifer, Professor of Civil Engineering, University of Oklahoma, Norman, spoke on "Good Construction of Small Sewers."

A landscape architect, Mr. George M. Merrill, Department of Horticulture, Oklahoma A. and M. College, discussed at length "Sewage Treatment Plant Beautification." A discussion followed by Messrs. Will O. Doolittle, Superintendent of Parks, Tulsa, Ancel Love, Superintendent of the Water Department, Okmulgee, and H. F. Sprangle, Superintendent of Light and Water, Claremore.

Mr. Edward R. Stapley, Associate Professor of Civil Engineering, Oklahoma A. and M. College, talked on the subject of "Records for Sewage Treatment Plants."

Chief Sanitary Engineer V. M. Ehlers, Texas State Board of Health, Austin, Texas, presented "Sewage Treatment Methods Employed in Texas."

April 24 and 25 were devoted to classes in water and sewage treatment.

Central States Sewage Works Association
Fourth Annual Meeting

Madison, Wisconsin

May 22–23, 1931

The meeting opened at 10:00 A.M. on May 22, 1931, in the main conference room of the Hotel Loraine in Madison, Wisconsin.

There were 98 members and guests registered at this meeting.

The meeting was called to order by Dr. F. W. Mohlman, President of the Association. He, in turn, introduced Mr. L. F. Warrick, State Sanitary Engineer of Wisconsin, who introduced the following speakers: Honorable Henry A. Huber, Lieutenant-Governor of the State of Wisconsin, Mayor Schmedeman of the city of Madison and Professor F. E. Turneaure, Dean of the Engineering School of the University of Wisconsin.

Dr. Mohlman responded by speaking of the aims of the Association.

The technical program was started promptly at 10:30 by a very excellent discussion from W. A. Sperry of Aurora, Illinois, on "General Administration of Sewage Plants."

Gus H. Radebaugh of the Champaign-Urbana, Illinois, plant stressed Mr. Sperry's point on the necessity for an attractive and clean plant. He referred to the Urbana-Champaign bulletin for the report on "Five Years of Operation, Sewage Treatment Works, Urbana-Champaign Sanitary District." Mr. Radebaugh urged that every treatment plant publish a clear, clean-cut and accurate report of operation and finances so that the citizens would know what the plant was doing and how their money was being spent.

H. F. Ferguson, State Sanitary Engineer of Illinois, discussed "Sanitation and Conservation of Illinois Streams under the Illinois Sanitary Water Board Law." Dr. Mohlman suggested that he also tell of some of the most important investigations that had been made during the year. Mr. Ferguson told of the Fox River investigations from the State Line to Aurora, the pollution on the Kaskaskia River, and of the oil and salt water pollution at East St. Louis.

After Mr. Ferguson's paper, the group was taken to the Wisconsin Memorial Union Building on the campus of the University of Wisconsin for luncheon. A group picture was taken immediately after the luncheon.

The afternoon sessions were held in the lecture room of the hydraulic and sanitary engineering laboratory of the University.

"Sewage Disposal Problems in Minneapolis and St. Paul" was reviewed by J. A. Childs from both legal and sanitation standpoints.

A very interesting and instructive paper was presented by Prof. L. E. Noland of the University on "Protozoan Metabolism."

Dr. A. M. Buswell of the University of Illinois reviewed the "Biology of Activated Sludge."

"Significance of Micro-Organisms in Sewage Purification" was discussed by Robert Cramer, former chief engineer of the Milwaukee Sewerage Commission. His remarks were a reiteration of his paper presented in the March, 1931, issue of the *Journal of Industrial and Engineering Chemistry*.

Dr. Levine, who was scheduled to give his paper on Saturday morning, but was unable to remain until then, discussed "The Effects of Some Insecticides on Larvae and Adults of the Sewage Sprinkling-Filter Fly,

Psychoda alternata," by Max Levine and W. W. Frye. The most effective method of destroying the adult fly was by the use of pyrethrum mixed with kerosene.

Dr. Hatfield of the Decatur, Illinois, plant told of the results of "Operation of the Pre-Aeration Plant at Decatur." The results of three years work were summarized giving the results (1) under normal operation sludge returned but without sludge aeration, (2) operating the first two tanks for reaeration of sludge, and (3) operation without any returned sludge.

"The Use of Paddle Aerators in the Activated Sludge Process" was reviewed by Wayne A. Kivell of the Dorr Company.

Dr. Mohlman discussed a paper by Dr. Gail P. Edwards and himself on some "Preliminary Experiments on Thermophilic Digestion." Frank Bachmann of the Dorr Company discussed their work on thermophilic digestion at Aurora, Illinois.

"The Effect of Sewage Plant Effluents on Lakes and Streams" was presented by Dr. Domogalla.

The afternoon session adjourned at 6 o'clock and at 6:45 a banquet was held in the Pompeian room of the Hotel Loraine.

The first diversion was a humorous recitation by Bob De Haven and Dave Welloch on "This and That." Dr. Harper, head of the Wisconsin State Board of Health, was then introduced. Prof. W. C. Troutman of the Department of Dramatics of the University of Wisconsin gave a very interesting and humorous account of "Why We Go to the Movies." This was followed by a very short talk by Adolf Kanneberg, Chairman of the State Commission on Water Pollution.

Two movies were shown; one by L. F. Warrick on "The Present Status of Sewage Treatment in Wisconsin" and the other by Gus H. Radebaugh on "Illinois Citizens Answer to the Call of Her Streams."

The meeting Saturday morning opened at 9:30. A short business session was held prior to the technical session.

The first report was that of the secretary-treasurer who stated that the present membership in the Association was now one hundred and forty-two. The membership by states was as follows: Illinois, 80; Indiana, 22; Minnesota, 2; Wisconsin, 32; Ohio, 2; Missouri, 3; and South America, 1.

The financial condition of the Association is excellent. The total receipts amounted to $492.50 and the total expenditures $272.00. Taking into account checks returned, outstanding and to be deposited, the balance on hand May 20, 1931, amounted to $308.91.

Dr. Mohlman appointed the following committees: Auditing—Frank Bachmann, G. P. Edwards and W. A. Sperry. Resolutions—C. R. Velzey, Chas. Brossman, Gus. Radebaugh, E. C. Hurd and W. B. Walraven. Nominating—Lewis S. Finch, E. J. Beatty and E. E. Smith.

"Factors Affecting the Accuracy of the Oxygen-Consumed Test," by H. W. Ruf, was the first paper presented Saturday morning.

Dr. H. O. Halvorson presented a very interesting scientific paper on "The Recovery of Proteins from Packing-House Sewage by Super-Chlorination." It was found that treatment of these wastes was best accomplished by chlorine and that the chlorine-nitrogen ratio was most important in effecting complete precipitation. The optimum point was at a Cl/N ratio of 2.3.

Before presenting his paper Mr. Brossman told how much fun he had been getting out of the banquet and read a poem he had written the night before at the banquet.

A dramatic *Psychoda*
Went down in the sludge,
His thermophilic digestion
Made it sweeter than fudge.
Then a few zoögloea,
With a *cyclops* or two,
A culture of enzymes
And *amoeba* a few,
All were quickly devoured
But still not enough,
He hunted and grappled
With *Paramecium* rough.
Then Peritrichs, Heterotrichs
In rapid succession,
In fact *Protozoa*
Were his pet obsession.
The slaughter continued,
When Dr. Frye, bright and keen,
Wrote the *Psychoda's* epitaph,
With kerosene.

Mr. Brossman then showed how neat and attractive a sewage treatment plant could be made, if necessary, by presenting the paper "Working Out Sewage Problems for a Tuberculosis Hospital."

"The Action of Secondary-Tank Sludge in Imhoff Tanks" was discussed by H. E. Wilson of the Bloomington-Normal Plant.

Dr. Mohlman presented the paper by himself, E. Hurwitz and G. R. Barnett on "Dilution Water for the B. O. D. Determination." E. J. Theriault of the U. S. Public Health Service discussed the paper.

The last paper on the program was by O. Knechtges on "The Beneficial Effect of Mixing Packing-House and Domestic Sewage."

Following this paper a business session was held and the reports of the following committees presented: W. A. Sperry for the auditing committee; the nominating committee by Mr. Finch, and the resolutions committee by Mr. Velzey. The following officers were elected for next year:

President: L. F. Warrick, Madison, Wis. *First Vice-President:* C. K. Calvert, Indianapolis, Ind. *Second Vice-President:* H. F. Ferguson, Springfield, Ill. *Secretary-Treasurer:* Gus H. Radebaugh, Urbana, Ill.

On Saturday afternoon, the majority of the people visited the new Nine Springs Treatment Works and the old Burke Plant of the City of Madison.

Gus Radebaugh, *Secretary*

New York State Sewage Works Association Spring Meeting

Freeport, New York

June 5–6, 1931

The spring meeting of the New York State Sewage Works Association was held at the municipal building, Freeport, N. Y., June 5–6, 1931. One hundred seventy-five members, guests, wives and manufacturers were registered.

At the business meeting a brief announcement was made regarding two annual awards to be known as the Kenneth Allen Memorial awards for excellence in technical papers and for excellence in annual reports on plant operation.

The technical session in the morning was devoted to two comprehensive papers, one on "Present and Future Status of Sewerage and Sewage Treatment on Long Island" by A. F. Dappert, Assistant Sanitarian, New York State Department of Health, the discussion on which was opened by C. A. Holmquist, Director of the Division of Sanitation, New York State Department of Health; and the other on "Sanitary Engineering in a County Health Department" by R. E. Cook, Sanitary Engineer, Suffolk County Health Department. Discussion on the latter paper was opened by J. L. Barron, Sanitary Engineer, Westchester County Department of Health.

At the Round Table discussion in the afternoon, Earle B. Phelps opened the discussion on "What a Sewage Plant Operator Should Know;" Morris Cohn on "What Sewage Tests Can the Small Plant Operator Make?" John F. Skinner on "Advantages and Disadvantages of Covered Drying Beds," illustrated with large charts and photos; Horace H. Chase on "Advantages and Disadvantages of Covered Settling Tanks;" Weston Gavett on "Gas Collection from the Digestion of Activated Sludge at Rockville Center."

More than twenty manufacturers had exhibits on display which were excellently set up, and unusual interest was shown by those attending the meeting.

The Saturday morning inspection trip to the pumping stations and sewage treatment works of the villages of Freeport, Rockville Center and Garden City was most instructive owing to the varied problems and methods of treatment.

The high spot in the entertainment was the dinner dance at the Elks Club on Friday night, tendered the Association by the local committee. The principal speakers at the banquet were the Honorable Thomas A. McWhinney and Leonard C. L. Smith, Commissioner of the Department of Sanitation of New York City.

The local ladies' committee provided a sight-seeing trip for the ladies on Friday afternoon and a picnic and beach party for all at Jones Beach State Park on Saturday afternoon.

The meeting will go down in the history of the Association as an outstanding one in attendance and entertainment.

The next meeting of the Association will probably be held in Ithaca in mid-October.

A. S. Bedell, *Secretary*

Pennsylvania Sewage Works Association
Fifth Annual Conference

State College

June 23 and 24, 1931

The Fifth Annual Conference of the Pennsylvania Sewage Works Association was held at the Pennsylvania State College, State College, Pa., on Tuesday and Wednesday, June 23 and 24, 1931. The total registration of members and guests was 123, the membership of the Association at the time of the Conference being 130. The men were housed in two modern dormitories of the college—an arrangement which added much to the comfort and good fellowship of those attending the Conference.

The Tuesday morning session was opened with an address of welcome on behalf of the college by Prof. Elton D. Walker, Head, Department of Civil Engineering, who extended the freedom of the college to the members and their guests. Prof. Walker was followed by Frank E. Daniels, Chief, Industrial Waste Division, Pennsylvania Department of Health, Harrisburg, who presented a paper entitled "The Practical Operation of Sewage Disposal Plant Units." This paper contained valuable advice concerning operating procedure by an engineer of long experience in this work. The last paper of the morning session by Harry Krum, City Chemist, Allentown, Pa., described the new Imhoff tank-sprinkling filter sewage treatment plant now being completed at Allentown, replacing the Landreth Direct Oxidation Electrolytic System which was installed in 1921.

The afternoon session was devoted to sewer maintenance and operation. The first paper by Albert H. Mainwaring, Assistant Engineer, Bureau of Highways, Philadelphia, Pa., described the organization and method of operation of sewer maintenance work in Philadelphia. The same subject, but applying to smaller cities, was covered by Roy L. Phillips, City Engineer, Meadville, Pa.

C. F. Wertz of Fuller & McClintock, Engineers, Philadelphia, Pa., described simple tests which can be made by non-technical sewage treatment operators to give the information necessary for the intelligent

operation of their plants and at the same time provide valuable data for future design purposes.

H. M. Freeburn, District Engineer, Pennsylvania Department of Health, Philadelphia, Pa., presented a paper entitled "Admission of Industrial Wastes into Sewer Systems." He presented a very sane general classification of industrial wastes based upon their admissibility into public sewer systems, his paper evoking considerable discussion. The last paper of the afternoon session was presented by Grant M. Olewiler, Assistant Superintendent Health & Drainage, Lower Merion Township, Montgomery County, on "Sewer Rentals in Pennsylvania." Sewer rentals have been collected since 1905 in Lower Merion Township and his paper ably described the successful methods used by the township.

The Annual Conference Dinner was held Tuesday evening at the Nittany Lion Inn with 105 present. H. E. Moses, Assistant Chief Engineer, Pennsylvania Department of Health, led the Round Table discussion which followed an interesting talk by Prof. E. D. Walker of State College on his observations of unusual sewage treatment practices in southern and western states.

The Wednesday morning session was opened by F. S. Barckhoff, City Engineer, Salem, Ohio, who described the activated-sludge plant at Salem, Ohio. Mr. Barckhoff's experiences would seem to indicate that the activated-sludge type of plant is satisfactory for small cities. John R. Downes, Supervising Engineer, Plainfield-Dunellen, N. J., Sewage Treatment Works, Plainfield, N. J., presented an interesting paper describing the results of experimental work begun in 1925 on the heating of sludge in an earth digestion tank. The last paper of the session, "Effect of Sewage Discharge on Streams," was presented by H. W. Streeter, Sanitary Engineer, U. S. Public Health Service, Cincinnati, Ohio. Mr. Streeter pointed out that the addition of dilution water through tributaries less polluted than the main stream has been observed frequently to result in an increase, rather than a decrease, in the bacterial content of the main stream.

The business meeting of the Conference was held Tuesday morning and at this session the following officers were elected for the coming year:

President, L. W. Monroe, Ellwood City, Pa.; *First Vice-President*, R. O'Donnell, State College, Pa.; *Second Vice-President*, Harry Krum, Allentown, Pa.; *Editor*, J. R. Hoffert, Harrisburg, Pa.; *Secretary-Treasurer*, L. D. Matter, Kirby Health Center, Wilkes-Barre, Pa.

Messrs. C. A. Emerson, Jr., and H. E. Moses were reappointed as members of the Board of Control of the Federation of Sewage Works Associations.

At the business session appropriate action was taken to amend the Constitution so that the Editor will be included among the officers of the Association.

L. D. Matter, *Secretary-Treasurer*

Reviews and Abstracts

H. W. STREETER

The Composition of Pipes for Heating Sludge-Digestion Tanks

By F. Sierp

Technisches Gemeindeblatt, **34**, 9 (May 10, 1931)

Abstracted by G. P. Edwards

Recent work with thermophilic digestion has emphasized the problem of heating sludge. Imhoff and Blunk introduced hot water directly into the sludge, thus avoiding the use of expensive equipment. This method has been used successfully at Essen-Rellinghausen for some time. According to data from Fries, in 1927, 820 gallons of hot water was used daily to maintain a temperature of 20° C. in a digestion tank with a capacity of about 158,500 gallons. In this way cooling water from other operations may be used. The sludge is washed by the hot water and a uniform transference of heat to the sludge is obtained. The water used for heating is drawn as sludge liquor and purified biologically.

Prüss recommends heating the sludge in a small tank before addition to the digestion tank. The heated sludge is mixed with the ripe sludge by means of a screw pump. Experiments on heating by means of hot water which circulates through iron pipe have been carried on by Dr. Rudolfs for several months. This method was not successful since a layer gradually formed on the outside of the pipe, which he feared would gradually increase in thickness and diminish the efficiency. Rudolfs prefers to preheat the fresh solids directly with hot water or steam.

The oldest method for heating sludge tanks is by means of heating pipes which are placed in the lower part of the digestion tanks. The iron pipe used, however, was quickly corroded. Poor heat transfer and incrustation of the pipe discouraged the use of iron pipe.

Heating pipes are arranged along the outer walls of the lower parts of Dorr separate sludge-digestion tanks. Heilmann used copper coils arranged in a spiral form in the digestion tanks at Halle. Hot water at 70° to 80° C. flowed through the pipes and no incrustation appeared.

Since heating pipe has been shown to be advantageous, experiments were made to determine what kind of pipe is best, from the standpoint of corrosion and the effect of the metal on bacterial action. The experimental

conditions do not correspond entirely to those in plant operation, since the pipe was not heated. Four kinds of pipe were used:

1. Normal iron pipe,
2. Zinc-coated iron pipe,
3. Copper pipe,
4. Tin-coated copper pipe.

The price of pipe must be considered along with its capacity for resistance and heat conductance. If iron pipe is considered as a base of 1.0, the relative prices are approximately as follows: zinc-coated iron—1.4, copper—3, and tin-coated copper—4.5. The relatively high price of copper as compared with iron is partially equalized by its higher heat conductivity, which is 320 for copper and 56 for iron.

A piece of each type of pipe, about 4 inches long, was hung in a liter of sludge composed of equal parts of fresh solids and ripe sludge. The samples were digested at room temperature with a blank for a control. Gasification occurred only in the control. Probably the relatively small amount of sludge was so affected by the metal pipe that digestion was prevented.

In a second experiment, the same pieces of pipe were placed in 15-liter flasks which contained a mixture of 5.5 pounds of fresh solids, 5.5 pounds of digested sludge and 5.5 pounds of sludge liquor. The sludge digested equally well in all the flasks and digestion was complete in about six weeks. Then 2.2 pounds of screened fresh solids were added to each and digestion continued. In each flask, there were 301.5 grams of dry fresh solids and 197.5 grams of ripe sludge or a total of 499 grams of which 291.7 grams were organic.

As the following table shows, the sludge containing the copper pipe digested best. All samples containing pipe digested better than the blank. However, the blank gave a denser sludge, with 10.4 per cent solids, as compared with 8.6 per cent for the iron, 9.5 per cent for the zinc-coated iron, 8.0 per cent for the copper and 8.4 per cent for the tin-coated copper.

	Sludge Mixture	Sludge Mixture + Iron Pipe	Sludge Mixture + Zinc-Coated Iron Pipe	Sludge Mixture + Copper Pipe	Sludge Mixture + Tin-Coated Copper Pipe
Liters of gas	61.2	62.6	63.1	64.6	61.97
Grams of organic matter digested	104.7	117.3	111.9	120.4	109.3

After completion of digestion, the pieces of pipe were removed and examined for corrosion. The iron pipe was covered with a gray-black coating about 0.1 mm. thick. This coating when removed and treated with dilute acid formed both CO_2 and H_2S. The zinc-coated iron pipe was not attacked. The copper pipe was corroded very badly. Scales of copper formed and were cracked off, permitting further corrosion.

In conclusion, the experiment showed that copper is attacked most rapidly and iron somewhat less. Zinc-coated iron and tin-coated copper were not corroded.

The Ruhrverband

BY DR.-ING. K. IMHOFF

REVIEWED BY G. P. EDWARDS

Dr. Imhoff has written a very interesting booklet, "Der Ruhrverband," published by Carl Heymans Verlag, Berlin, in 1930, which gives a brief survey of the many activities of the Ruhrverband. The booklet is attractively arranged and printed in a heavy type which is easily read. It is well illustrated, containing a hundred pictures, diagrams and maps. Nearly every type of sewage treatment is described and illustrated by diagrams and photographs. Tables which present data on the various treatment plants include contributing population, industrial wastes, kind of treatment, amount of sewage, detention period, etc.; other tables summarize data on pumping stations and power plants. A statement of operating income and expense is included.

The Ruhrverband is composed of twenty-two cities and communities and includes a population of 1,434,640. The district is highly industrial, supporting 61 coal mines, which yield twelve million tons of coal per year, iron and metal works, tanneries, weaving and textile factories and paper mills. The Ruhr River is used as a water supply for about 3,500,000 people and must be kept as free from pollution as possible.

The Association was formed in 1913 but its building program was started in March, 1914. At that time, the management was combined with that of the Emschergenossenschaft. Since 1922, the management of the two organizations has been separate. The construction program was interrupted by the War and little was done till 1923.

The Ruhr River is kept clean by a network of sewage treatment plants. Due to the importance of the Ruhr as a water supply, it was originally planned to build a large number of biological treatment plants. Later, plans to construct eight artificial lakes, two of which have now been completed, will make some of these plants unnecessary. Hengsteysee, a lake about 0.6 square mile in area, was completed in 1927 and Harkortsee, about 0.5 square mile, was finished in 1931. Conditions are so different in various parts of the Ruhr Valley that almost all known methods of sewage purification are used. Included in the sixty-nine plants for the treatment of sewage or industrial wastes, there are twenty-eight Imhoff installations, five separate sludge-digestion plants and nine with biological treatment, of which three have submerged contact aerators, one activated sludge, three

combinations of submerged contact aerators and activated sludge, one fish pond and one sprinkling filter. Gas is collected at sixteen plants. At seventeen plants, there are under-drained settling basins which are constructed like sludge-drying beds but are operated alternately as sedimentation units and sludge-drying units. Phenols, wool fat and iron sulphate are among the substances recovered from industrial wastes.

Three water-power plants are in operation. Two on Hengsteysee generate 24 million kilowatt hours per year and the newer one on Harkortsee generates annually 28 million kilowatt hours.

Activated Sludge for Small Communities

BY W. SCHÜTZ

Gesundheits-Ingenieur, **54**, 278 (May 2, 1931)

ABSTRACTED BY G. P. EDWARDS

Activated sludge is generally considered suitable only for communities of more than 50,000 inhabitants, because such treatment requires careful supervision by scientifically trained persons. The cost of this supervision, in addition to the cost of air compressors, pumps and other equipment, makes the treatment too expensive.

Activated sludge is practical for small communities if previously tested simple methods and apparatus are used. A small plant is not the place for experimental or developmental work.

A small activated-sludge plant has been built for Rabenstein, a city of about 3000 people, located near Chemnitz. There is a daily sewage flow, including industrial wastes from dye works and sewage from a hospital, of about 95,000 gallons or nearly 8000 gallons per hour. Only the Riedbach, a very small stream, is available to receive the effluent; consequently, the sewage must be well purified. Since the only available site for the plant was in a well-populated section, the activated-sludge process was chosen in order to avoid odors and other nuisances.

The plant consists of a grit chamber, a Kremer settling tank, with a capacity of 13,200 gallons, and a sludge-digestion tank, with a capacity of 4590 cubic feet, which is located underneath the settling tank. The aeration tank is divided into two parts and has a total capacity of 47,550 gallons. The secondary-settling tank holds 13,200 gallons. In addition, there are pumps, a machine house and a chlorinating apparatus.

The detention periods are: preliminary-settling tank—1.66 hours, aeration tank—6 hours, and secondary-settling tank—1.66 hours.

During storms, five times the dry weather flow can be clarified mechanically. The excess flows directly to the Riedbach. The maximum dry-

weather flow only is treated in the aeration tanks but, during storms, the flow in the Riedbach is large enough to dilute the excess settled sewage successfully.

The Kremer aeration tank was considered superior to the Hurd system or the paddle-wheel arrangement because of its simplicity. The Prussian Landesanstalt für Wasser, Boden und Luft Hygiene reported that aeration and circulation with the Kremer air circulator was extraordinarily simple and attractive, since it is easily serviced. There are no moving parts in the sewage and no air compressor is necessary, as a simple ventilator is sufficent.

The efficiency, based on permanganate consumed, amounts to 65 per cent. About 96.6 per cent suspended matter is removed and the volatile part of the suspended matter is reduced 96.2 per cent. Nitrates are detectable in the effluent. All effluent samples are stable and clear, have a yellow color and have a slightly earthy odor.

In the aeration tank, compressed air is introduced about three feet below the surface, through a round nozzle fitted on a vertical pipe. In this way, liquid from the bottom is sucked in through the pipe, aerated and distributed over the surface of the tank, causing continuous circulation and intimate mixing of sewage with air. The openings in the aerator are large enough so that they do not become clogged. An aerator is installed in the center of each hopper. The tank is divided longitudinally into two parts and each section can be used either alternately or at the same time as the other. Compressed air at a pressure of about 0.1 atmosphere is furnished by a blower directly connected with a motor. A second blower is held in reserve. Oil and dust filters are not necessary.

With this low pressure of only 0.1 atmosphere, 4250 to 5300 cubic feet of air per hour can be generated with one horsepower. With a ratio of sewage to air of 1 to 10, one horsepower can purify 3170 to 3960 gallons of sewage.

The per capita cost, for an estimated population of 3600, is about $4.50 which is comparatively low.

The Rabenstein treatment plant has been in operation more than six months. With its small energy requirement, the supervision is simple. A skilful mechanic should inspect the plant twice daily. The effluent from the plant is completely clear and stable.

The Sewage Treatment Plant and Expansion of the Sewerage System in Pössneck

BY FR. A. GROSS

Gesundheits-Ingenieur, **54**, 209 (April 4, 1931)

ABSTRACTED BY G. P. EDWARDS

Pössneck, a city in Thuringia of about 15,000 inhabitants, owes its development to textile and leather industries. The city lies in a valley through which a small stream, the Kotschau, flows. The Kotschau unites with the Orla in the eastern part of the city. The Kotschau has an average flow of about 4 cu. ft. per second and the Orla, including the Kotschau, 45 cu. ft. per second. It is evident that, without treatment of sewage and industrial wastes, the Kotschau and the Orla must be badly polluted.

In 1927–29, a new sewer about 4360 yards long was built to take care of the industrial wastes. Previously they had been discharged directly into the Kotschau. Sewage measurements showed an average dry-weather flow of about 6.7 cu. ft. per second. The sewage, when received at the treatment plant, is usually septic, gray-brown or yellow in color and contains about 248 p. p. m. suspended solids, of which 195 p. p. m. are volatile. About 600 grams of dry solids per capita per day are obtained. This is from 6 to 10 times the normal amount from strictly human sewage.

The treatment plant consists of a coarse screen, grit chamber, shallow settling tank and separate-digestion tanks. The coarse screen placed at the junction of the two sewers has 1.18-inch slots. It is cleaned by hand and about 0.65 cubic yard of screenings is obtained daily. The grit chamber, which is about 74 feet long, consists of two chambers, each 4.6 feet wide, and a bypass channel. During dry weather, the flow through the grit chamber is about one foot per second. About 7.85 cubic yards of grit are removed each week by hand.

The settling tank is square, 82.5 feet on a side, with rounded corners. There is a maximum effective depth of 8.1 feet. The floor has a slope of 1:12. Differing from the usual settling tank, this tank contains a concentrating tank similar to that used at the Essen-Nord plant (Emschergenossenschaft) and at the Essen-Rellinghausen plant (Ruhrverband). In order to equalize the flow, the sewage enters the tank through seventeen slanting slots at the south wall. The sewage is then forced by a baffle parallel to the tank wall to the deepest part of the tank. The tank has a capacity of about 528,000 gallons and, with a maximum dry-weather flow of about 7.7 cu. ft. per second, there is a detention period of about $2^1/_2$ hours, with a theoretical speed of about 1 inch per second. At the north side of the tank, the sewage passes over an overflow weir extending over the entire width of the tank directly to the Kotschau. Dorr equipment

forces the settled solids into the concentrating chamber, which extends 13.1 feet below the bottom of the settling tank. This concentrating chamber has a capacity of 706 cubic feet. The Dorr apparatus operates 3 hours in the morning and 1 hour in the afternoon. About 27 minutes are required for one rotation. The Dorr apparatus also scrapes the scum to a corner, from where it is removed.

The digestion tank, with a diameter of 44.3 feet, contains three hoppers. The maximum inside depth is 40.3 feet. A three-bladed screw pump circulates the sludge and destroys the scum. The pipe for the screw pump and the sludge draw-off pipe terminate at the bottom of the hopper. Two hours' operation of the screw pump daily have been sufficient to prevent scum formation. This operation has been divided into three periods: one, thirty minutes in length; and two, forty-five minutes. The direction of pumping is almost always from bottom to top, although the direction may be reversed. The screw-pump circulator not only prevents scum formation but also speeds up sludge digestion.

If a digestion period of two months and daily sludge additions of 2118 cubic feet are assumed, then, considering the reduction in solids due to digestion, 95,300 cubic feet of sludge would remain. The Pössneck digestion tank has a total effective capacity of about 42,360 cubic feet, giving a calculated digestion period of only four weeks. The actual digestion period is somewhat longer than this, since 2118 cubic feet of sludge per day are not always received, especially on Sundays and holidays. However, the unusually high temperature of the sewage and the digestion room has favored digestion. No difficulties have appeared. The drawn sludge is black and has a tarry odor. The side walls of the tank are covered with earth to prevent heat losses. The top is made gas-tight, with a lead cover.

Concentrated sludge is pumped from the settling tank for thirty minutes twice daily. The digested sludge is forced by compressed air to the sludge ponds. The sludge liquor is fed back to the settling tank.

About 14,120 cubic feet of gas is collected daily. This is purified and part of it is used for heating the machine house. The remainder is used in the city supply.

The plant which was put into operation during the middle of 1930 had operated satisfactorily after temporary difficulties in the digestion tank were overcome.

Biological purification was not considered necessary, since the Orla is not important as a water supply for drinking or industrial purposes. The plant effluent is diluted 6 to 20 times in the Orla, which is quite sufficient.

Purification of Textile Wastes

BY DR.-ING. SCHMEITZNER

Gesundheits-Ingenieur, **54**, 315 (May 16, 1931)

ABSTRACTED BY G. P. EDWARDS

The treatment of textile wastes, especially from bleaching or dyeing, is very difficult because the wastes have a high oxygen demand; they require neutralization; they are difficultly treated by biological methods; and the finely divided dyestuffs are hard to separate. The sludge obtained cannot be handled in the same way as that from normal municipal treatment plants. When small amounts of textile wastes are discharged into municipal sewage plants, they can be treated without difficulty, since the high bacterial content of feces facilitates the destruction of the organic matter.

The twin city, Iwanowo-Wosnesiensk, the center of the Russian textile industry, is now in the midst of a large industrial expansion. Old factories are being enlarged and new ones are being built. The city is building sewers, streets and bridges. The total sewage flow is about 22,200,000 gallons per day, of which only 10 per cent is domestic sewage, containing feces. The flow in the slowly moving Uwod River is so small that occasionally the dilution is not much more than 1 to 1. Since the Russian people are accustomed to taking their drinking water directly from the rivers and, as the fish serve as a food supply, it is necessary for Iwanowo-Wasnesiensk to purify its sewage as completely as possible.

An experimental plant to treat about 3960 gallons of sewage per hour is being built. The flow will be divided equally into three parts. The first part will pass through a circular settling tank, having a 4-hour detention period, in which neutralization of the different wastes and separation of the sludge occur. The settled sewage then flows through a two-stage absorption filter. The first stage of the filter is a contact bed, which can be changed into a sprinkling filter with channels for distribution. The second stage is a sprinkling filter with distribution by means of nozzles. Crushed peat or cinders from peat will be used as filtering material. The property of peat of holding water will have some effect on the permissible load or contact period.

The second and third parts will flow through settling and equalizing tanks which have a detention period of 4 hours. The second part will then be treated with iron sulphate and aerated. Aluminum sulphate will then be added and the sewage settled 2 hours.

The third part, after settling, will be mixed with powdered lignite, aerated and settled 1 hour. Since it was found that about 20 per cent of the finely divided coal remained in the sewage, aluminum sulphate will be added and the sewage settled 5 hours.

The effluent from the two last processes may then be treated biologically by a sand filter, a sprinkling filter, submerged contact aerators or activated sludge. Provision will be made for the use of 3-, 6- or 9-hour aeration periods.

The preliminary-settled sludge may be dried on beds mechanically or by heat. The chemically precipitated sludge will be dried mechanically or by heat.

The preliminary-settling tanks and the absorption filters will be placed in a building. The tanks for chemical treatment are to be placed in the main building with the laboratory, blowers, heating equipment and apparatus for drying sludge. The tanks for secondary biological treatment are not covered and, during cold weather, they will be covered with wood covers or not operated.

Meeting of the German Chemical Society—Water Chemistry Section, Vienna, May 27–30, 1931

Gesundheits-Ingenieur, **54**, 413 (June 27, 1931)

ABSTRACTED BY G. P. EDWARDS

The forty-fourth meeting of the German Chemical Society was held in Vienna, May 27–30, 1931. In the section for water chemistry, Dr. J. Swiet of Amsterdam discussed his investigations on the factors which influence the survival of bacteria during the progress of the self-purification of streams. Dr. G. Ebeling from the Landesanstalt für Fischerei in Berlin-Friedrichshagen discussed the effect of the chlorination of sewage on water suitable for fish. He reported some new results from fishery experiments and cellulose factory wastes. Dr. R. von der Leeden, Neumünster, presented a paper on clarification apparatus with flow regulation. F. Mieder discussed three years' operation of the Leipzig clarification tanks. Mr. Mieder and Dr. K. Viehl presented data on recent results from the experimental activated-sludge plant at Leipzig. Dr. H. Bach of Essen spoke on "How Should One Investigate Sewage Treatment Plants?"

The papers with discussions will be presented in the annual publication *Vom Wasser*, Vol. V, which will be published in December, 1931.

Some Considerations in the Oxidation of Sewage

BY F. R. O'SHAUGHNESSY

Presented at Association of Managers of Sewage Disposal Works, Birmingham, England, July 3, 1931

ABSTRACTED BY G. P. EDWARDS

The oxidation of sewage by different methods has been carried on experimentally at Birmingham for many years. A small experimental plant built in 1921 consisted of a tank with a capacity of 750 gallons (Imp.), and a small centrifugal pump to lift sewage into a shallow concrete gently sloping channel 320 feet long by 2 feet 6 inches wide, a layer of small pebbles being placed on the sloping floor of the channel. The channel discharged into the tank. Sewage passing down the race in as short a period as 5 minutes contained a definite though minute amount of nitrate, which disappeared in the earlier stages of the circulation of sewage as long as any appreciable amount of raw sewage remained in the tank. The sewage was circulated continuously for long periods.

It was found that impurities were rather rapidly transferred from the liquid to the pebbles. Oxidized nitrogen, with subsequent reduction, was noticed in the earlier stages, with a slow but steady increase in nitrification after two days, indicating steady aerobic transformation of the organic matter deposited on the gravel particles in the channel. Stabilization of the liquid appeared to be complete in a few days, but stabilization of the sludge took much longer.

The character of the action was entirely different if the rate of addition of oxidizable impurities caused septic action to set in. As long as aerobic conditions are maintained, rapid transference of the polluting material from the liquid to the solid phase is obtained. If anaerobic conditions intervene, the action may be reversed and the polluting matter tends to pass from the solid to the liquid. The intermediate state, when anaerobic conditions are overtaking aerobic conditions, seems to be marked always by more or less rapid development of filamentous growths. This has been observed in operation of the bio-flocculation plants. Experience indicates that once a definite biological balance has been established in a sludge, it tends, with lapse of time, to become stabilized and is difficult to upset. This holds true for either floc or filamentous growth.

Various dilutions of settled sewage were aerated with 10 per cent by volume of good activated sludge. The analyses of portions drawn off after 1, 8 and 16 hours showed a very rapid purification at the beginning and an exceedingly slow rate of change after eight hours' treatment.

Various experiments on the oxidation of sewage have shown that even very septic sewage could be deodorized in about twenty minutes by inten-

sive aeration by the activated-sludge process, using either diffused air or mechanical agitation. The liquor also became more suitable for oxidation by sprinkling filters. A battery of experimental filters was installed. The filter medium was taken from the large filters at Minworth and was heavily coated with slimy sludge when used. A layer of pea gravel was placed on top to improve distribution. A description of the filters with treatment and analysis of the effluent is shown in the following table.

Minworth Filters	Depth	Volume of Sewage per Cubic Yard per Day, Gallons	Volume of Sewage per Acre per Day (Imp.), Gallons	Analysis of Effluent: Free NH_3, P. p. m.	Analysis of Effluent: Oxidized Nitrogen, P. p. m.	Analysis of Effluent: Oxygen Absorbed $KMnO_4$, P. p. m.
Experimental filters	6	50–60	600,000	*	*	*
(A) Feb. 5, 1922, gravel	6	160	1,500,000	10.7	16.0	7.9
(B) Feb. 5, 1922, slag	6	137	1,250,000	24.4	20.0	9.8
(C) Feb. 5, 1922, slag	9	188	2,275,000	26.5	9.0	9.5
(D) Feb. 5, 1922, slag	12	145	2,800,000	32.9	16.0	10.8
(A) Sept. 5, 1922, gravel	6	80	750,000	14.4	10.0	10.5
(B) Sept. 5, 1922, slag	6	120	1,100,000	28.1	11.0	11.9
(C) Sept. 5, 1922, slag	9	180	2,180,000	36.1	10.0	11.3
(D) Sept. 5, 1922, slag	12	108	2,000,000	30.9	12.0	11.3

* Analyses not given.

Passage of clarified effluent from the bio-flocculation plant completely eliminated the large masses of highly organic sludge which were put into each of the filters with the influent. It has been found that the bio-flocculation effluent applied at twice the rate of unclarified sewage to clogged filter bed will be purified and will gradually de-sludge the bed.

The present bio-flocculation Plant I consists of a set of continuous-flow channels which the sewage traverses in series, giving a one-hour detention period. Propulsion is augmented by large paddles and aeration assisted by diffuser plates. The motion of the water is along a spiral flow. The conditioning tanks consist partly of fifteen pyramidal bays furnished with Simplex aerators and a large tank fitted with porous plates, ridge-and-furrow style, laid 7 feet 3 inches below the water level. The effluent from the bio-flocculation tank is distributed over sprinkling filters with spray jets.

In Plant II, aeration is effected by air from diffuser plates laid 10 feet below water level in ridge and furrow. The following data for the two plants is typical:

	Plant I	Plant II
Average daily flow, million gallons	7.5	12
Horse-power per million gallons of sewage per day	17–18	9–10
Horse-power per million gallons of sludge per day	50–55	46.3
Ratio—sludge return to sewage	1:5.2	1:8.3
Sludge concentration in the conditioning tanks:		
18 hrs.' settlement, per cent	16.0	15.4
1 hr. settlement, per cent	30.0	53.0

	Plant I	Plant II
Sludge returned by pump, gallons (Imp.) per hour	60,000	60,000
Detention period in mechanically agitated tanks, hours	13.5	...
Detention period in diffused-air tanks, hours	8.3	8.75
Cu. ft. air per gallon (Imp.), sewage-diffused-air tanks	...	0.17
Cu. ft. air per gallon (Imp.), sludge-diffused-air tanks	1.65	1.40

The biochemical oxygen demand of the raw sewage and effluents is as follows:

	B. O. D., P. p. m.
Raw sewage	188.9
Bio-flocculation plant No. 1 effluent	101.4
Corresponding sprinkling-filter effluent	11.0
Bio-flocculation plant No. 2 effluent	108.3
Corresponding sprinkling-filter effluent	17.8
Settled sewage on sprinkling-filter effluent	19.5

One-hour detention period in the flocculation tank was chosen because very septic sewage was completely deodorized in an hour, dissolved oxygen and oxidized nitrogen could not always be found before an hour, and forty to fifty per cent purification could be obtained in this time. Good results have been obtained by using small amounts such as 2 to 5 per cent of activated sludge. Purification consists first of a rapid adsorption process and then a slower oxidation of the absorbed substances.

The Operation of the Activated-Sludge Plant at Reading

BY A. S. PARSONS AND HAROLD WILSON

The Surveyor, 79, 647–648 (June 19, 1931), and 79, 689–690 (June 26, 1931)

ABSTRACTED BY E. HURWITZ

The Reading plant was constructed in 1925 to care for a population of 100,000 people with a sewage flow of 3,000,000 to 4,000,000 gallons (Imp.) per day. The plant consists essentially of detritus tanks, aeration tanks, sludge concentration tanks and sludge filters. The unusual feature of the plant is the great depth of the aeration tanks. The plant was operated by Activated Sludge, Limited, during 1925, 1926 and 1927. The first trials were made with a flow at the rate of 5,750,000 g. p. d. but it was soon discovered that the plant could handle only 1,250,000 g. p. d. satisfactorily. In casting about for the reason, velocity tests were run and small-scale experiments were made to determine the length of time necessary to purify Reading sewage, and also the effect of gas-house and brewery wastes. It was found that the liquid traveled through the spiral-flow aeration tanks with velocities ranging from one-third to three times the theoretically correct rate.

The small scale tests showed that at least seven hours were necessary to purify Reading sewage and that the trade wastes had no detrimental biological effects.

Part of the plant was altered to the ridge-and-furrow type of floor. Further tests with sewage containing gas liquor showed that the plant could treat only 750,000 g. p. d. Without the liquor, 1,000,000 g. p. d. could be handled. It was concluded that the alteration of one-eighth of the plant to the ridge-and-furrow method made no appreciable improvement. However, this system was extended to the second half of the first aeration unit and to the whole of the second, putting about one-half the plant under this system.

It is recognized at Reading that the condition of the sludge is an important factor in efficient plant control. Microscopic examination of the sludge and determination of the dissolved oxygen in solution give a fair conception of the condition of the sludge and flows to the plant are altered only as the sludge indicates whether the plant is overburdened or not worked hard enough.

It was found at Reading that a satisfactory effluent can be produced with little or no nitrate and that often high nitrification is obtained only at the sacrifice of clarification. Consequently, the Reading plant is operated so as to produce a sludge with the maximum possible clarification, no regard being paid to nitrification so long as a stable effluent is obtained.

It was hoped that by installing preliminary-settling tanks, it would be possible to increase the flow to the activated-sludge tanks, but this experiment, like others tried at Reading, failed.

The work at Reading showed the possibility of using activated-sludge treatment as partial treatment to be followed by percolating filters. A semi-plant-scale experiment gave gratifying results and arrangements have been made to operate the whole activated-sludge plant on partial treatment lines as a summer experiment.

Experiments on digestion of sludge are also under way. A tank large enough to permit digestion of one-third the total sludge output has been made available and 600,000 gallons of ripe sludge has been prepared to start digestion.

Tests on depths of percolating filters and effects of different filter media show that a ten-foot filter is superior to a six-foot filter, and that flint gravel is as effective as clinker.

In commenting on the paper by Parsons and Wilson, Mr. F. C. Temple (Jamshedpur, India) remarked that it was true that almost every device for sewage disposal had suffered from the enthusiasm of its exponents. He thought it was not surprising that better results were obtained with the ridge-and-furrow system than with the spiral-flow, inasmuch as the former had twice the diffuser area to the same floor area.

Mr. H. C. Whitehead remarked that although the Reading plant was and still is a source of expense and anxiety to its owners, it has furnished extremely valuable additions to the knowledge of sewage purification and has been the means of improving the design of many of the later, more successful plants.

Mr. F. R. O'Shaughnessy remarked that partial treatment by activated sludge followed by percolating beds seemed likely to solve the difficulties at Reading. The results of these experiments were in complete accord with his own work.

Treatment of Sewage Discharged into the Sea

BY H. C. H. SHENTON

The Surveyor, **70**, 14 (July 3, 1931)

ABSTRACTED BY DOROTHY W. HARDT

Although the importance of the pollution of beaches, which may result from discharging sewage at sea, is not universally recognized as yet, it is gradually becoming quite obvious. Mr. Whipple's experiments at Milwaukee showed that both temperature and winds are responsible for shallow and deep movements of water. The mere distance of an outfall from shore is not the only factor in prevention of pollution of beaches. This has often been illustrated by the nuisance on beaches created by oil and tar discarded far out at sea.

England has been slow to realize the possibilities of pollution of its beaches, although it has brought about filtration and chlorination of bath water; while America has given considerable attention to the matter.

The usual practice has been to bring about some separation of solids and liquid and to chlorinate the effluent before its discharge. In some cases, however, merely disintegration and chlorination has proved satisfactory. Reported records of chlorination indicate that the amount of chlorine required varies widely according to the character of the sewage and the degree of treatment.

Screening and subsequent chlorination does not appear to be an ideal method of treatment. With a properly designed plant, separation and treatment of the solid matter in digestion tanks and chlorination of the effluent before it has become septic should give more practical and economical results. Such removals of solids as the 80 per cent removal at Catterick Camp and treatments of effluents recommended by Dr. Prüss, in Germany, and others in America, are very suitable. Mr. E. B. Besselievre of New York has recently described a treatment plant located below a park and embodying all new features, including gas collection and utilization. The

gas generated can be used for the production of power or the sterilizing agent.

The agent (electrolyzed sea water) has long been used for disinfection at sea. Approximately 6 to 7 gallons containing 2000 to 2500 p. p. m. available chlorine can be produced within five minutes. Dr. Eric Rideal (1914) found that 3 to 4 kilowatts were consumed in producing a pound of available chlorine and that about 300 pounds of available chlorine could be obtained from 100,000 pounds (10,000 gallons) of sea water. This quantity would be sufficient to treat about 3,000,000 gallons of sewage-tank effluent, requiring 10 p. p. m., or a much larger quantity of more highly purified effluent.

The activated-sludge process is becoming more and more important as a means of preparing an effluent suitable for further treatment on filters or by a second stage of the same process; and, under given conditions, it is excellent for treating sewage to be discharged at sea and has been adopted abroad for that purpose. The ease of sterilization of such an effluent and the minimum power requirement are strong points in favor of the process.

Discussion

Mr. Sandford Fawcett, President (Institution of Sanitary Engineers, London), felt that sterilizing sewage would entail the difficulty of sludge removal at considerable expense. He saw two aspects to the case, the prevention of nuisance from the discharge of crude sewage and the prevention of bacterial contamination.

Mr. G. T. Cotterell also considered the cost of sludge digestion to be expensive, particularly for a small district.

Mr. Lionel Jenkins was in favor of carrying outfalls farther out to sea, where purification by dilution and dispersion would be almost inevitable, as the most satisfactory and economical method of handling sewage at seaside resorts. In the case of towns on estuaries, he thought treatment more practicable.

Mr. Balsam brought out the connection between the sludge-digestion process and sterilization by means of electrolytic hypochlorite, by the statement that "from $^3/_4$ to 1 horse-power per day could be produced by the gas generated by the sludge of a population of 1000, and the relation between this power and that required in order to produce the sterilizing agent was most important."

Future Possibilities in Sewage Disposal

BY H. C. H. SHENTON

The Surveyor, 79, 381-382 (March 27, 1931)

ABSTRACTED BY C. T. CARNAHAN

The collection and utilization of gas from sewage sludge is an accomplished fact in many places. At Birmingham there is a total of 950 b. h. p. developed in this way. With correctly designed, equipped and operated digestion tanks sufficient gas can be generated to run the disposal works.

With the Prüss system, from 0.5 to 0.7 cu. ft. of gas per capita per day is produced from sedimentation tank sludge. This amount is greater if activated sludge is mixed with the sedimentation tank sludge.

Heating the digestion tanks reduces the size of the tanks required for complete digestion and accelerates the gas production by speeding up the biological activity and so renders the gas production system more economical from both the construction and the operation viewpoints.

An ideal sewage disposal system would be somewhat as follows:

(1) A preliminary settling tank from which sludge is discharged to a separate digestion tank.

(2) Activated-sludge tanks in one or two stages as required by the sewage. The advantages of double stage treatment for strong sewages have been abundantly proved.

(3) An arrangement for mixing the excess activated sludge with the crude sewage as it enters the preliminary settling tanks.

(4) Separate sludge-digestion tank with arrangements for mixing and heating sludge to a temperature of 75° to 80° F., and for collection of the gases evolved for power and heating purposes.

(5) Sludge drying beds for the dewatering of the completely digested sludge.

(6) Power plant driven by the evolved gases.

Plants designed and built along these lines have already been put to use in Germany and America.

Those who possess the greatest knowledge of the practical application of the activated-sludge, sludge digestion and gas production processes are undoubtedly the manufacturing firms who hold the patents and install the plants. The manufacturers are not always able to give the best advice with regard to sewage disposal as their engineers are specialized and their outlook is generally somewhat biased. Cities and towns need advice from engineers with more general knowledge and experience who must be able to prove the economy of the processes or methods they propose to install.

The remainder of the article is a summary of the principles of separate sludge digestion with the collection of the evolved gases. The author also

calls attention to the advisability of double stage aeration when treating strong sewages, and where separate sludge digestion is practised with gas utilization for power, this method can be used very economically and advantageously.

The Cheltenham Sewage Purification Works

By J. S. Pickering

The Surveyor, 79, 559–560 (May 22, 1931)

Abstracted by C. T. Carnahan

The Cheltenham sewage disposal works have been in operation for 16 years. The corporation owns two sewage farms, one at Hayden having an area of 200 acres, and one at Barn Farm, with about 130 acres. The dry weather flow is about 2 m. g. d. from a population of 55,000.

The sewage disposal plant at Hayden is capable of handling $1^3/_4$ m. g. d. of dry-weather flow and about 3 times that volume of wet-weather flow. The sewage farm at Hayden handles only storm water at a rate of from 3 to 6 times the dry-weather flow. The Barn Farm handles 250,000 gal. daily by means of broad irrigation.

The sewage purification works consist of detritus tanks, settling tanks, trickling filters and humus tanks.

The sewage flows through a small sump where the heaviest mineral matter is removed and then flows to the hopper-bottomed detritus tanks where the finer detritus is removed. The sludge from the detritus tanks is conveyed to a sump from which it is pumped by two sludge pumps with a total capacity of 150 g. p. m.

The 12 settling tanks are arranged to give three parallel streams of sewage. They have a total capacity of 940,000 gal. providing a settling period of 13 hours based on average flow. The tanks are circular and are provided with hand-operated sludge scrapers. The tank effluent is well clarified and the scrapers have worked efficiently in the removal of the sludge, with very small upkeep cost.

There are 14 filters, each 101 feet in diameter. Ten of these filters are in separate units, but 4 filters added in 1926 were made in one group. The filtering medium is made up of $1^1/_2$ in. to $^3/_4$ in. crushed granite, 4 ft. 6 in. deep. The filtration rate is about 94 gal. per cu. yd. daily. The original plan was for 80 gal. per cu. yd. dry-weather dosage but the rate has been increased without appreciably reducing the quality of the effluent.

There are 4 humus tanks with a combined capacity of about 250,000 gallons. The tanks have hopper bottoms and the humus is removed by the hydrostatic pressure of the liquid in the tanks to an open chamber at

the surface, whence it is discharged into the outfall sewer or into the sludge well by a compressed air ejector.

Sludge is disposed of by pumping to private farms and utilizing it for fertilizer after drainage in lagoons made of fine ashes. The disposal of sludge by this method is a mutual advantage. The corporation is relieved of dealing with it at the works and the farmers obtain a good fertilizer. No sludge was accumulated at the works for a period of 15 years. Similar methods of sludge disposal might well be used at other works which are situated near agricultural areas for economical disposal of sludge.

The treatment of gas-works liquors is handled at Cheltenham by regulating the flow of the liquor from the gas works to an amount not to exceed 0.5 per cent of the average dry-weather flow. The waste liquors are stored in tanks at the works and are discharged into the sewers through a V-notched weir. Records of the discharge are kept, and are forwarded to the sewage disposal works each month. The rate of flow has always been kept below the maximum discharge allowed.

Purification Works		Net Cost
Loans, rates, taxes and insurance	$20,000	
Working expenses	6,800	
	$26,800	
Less contributions from Charlton Kings and Rural district council	5,800	$21,000
Sewage Farm		
Loans, rates, taxes and insurance	4,810	
Repairs, etc.	490	
Irrigation, drainage, etc.	880	
	$ 6,180	
Less rent	2,560	3,620
		$24,620

The plant effluent has always been satisfactory and well above the standard. The sludge is economically disposed of without nuisance. Daily filter and humus tank effluent samples have been stored for two weeks without signs of putrefaction. The filters are in excellent condition and show not the slightest reduction in efficiency. Two of the beds have been in operation for 20 years, eight for 15 years and four for 4 years. The good condition of the filters is due mainly to the excellent quality of the settling tank effluent and to the care with which this effluent is distributed to the filters. The flow to each filter is carefully regulated by means of V-notch weirs and the discharge rates and volumes are automatically recorded as are the number of revolutions of the distributors.

The sewage farms are now leased at an annual rental of $2560. The

corporation supplies labor for irrigation purposes and keeps up the repairs and the carriage and drainage systems at an annual cost of about $1360 yearly, thus creating a small annual surplus. Hayden farm is now used only for disposal of storm water and is irrigated when necessary for fertilizing purposes.

The cost of the purification works is about $312,000. The accompanying table gives the present annual cost of sewage disposal.

Sewage Disposal at Barnsley

The Surveyor, **79**, 573 (May 22, 1931)

ABSTRACTED BY E. HURWITZ

The Barnsley sewage disposal works is made up of two units, the high-level works which receive the sewage from the higher sections of the county borough and the low-level works.

The high-level works are designed to treat 1,250,000 gallons per day. At present only 850,000 g. p. d., of which about seven per cent is trade wastes, reaches this plant. The sewage is treated first in four detritus tanks which have a capacity of 5850 gallons each. The sludge from these tanks is discharged onto the drying beds once a week. The sewage then flows into four sedimentation tanks. The first two of these tanks work in parallel and feed the first filter battery; the second set feeds the second filter battery. The maximum capacity of each of these tanks is 134,000 gallons. The two filter batteries consist of sets of four and five filters each. Eight of these filters are each 100 feet in diameter; one is 120 feet. The filter effluent is clarified in four humus tanks with a capacity of 42,000 gallons each. The sludge is pumped onto the beds from these tanks daily during the summer and autumn, and three times a week during the rest of the year. The area of the drying beds receiving sludge from the detritus tanks is 1525 square yards; from the sedimentation basins, 3379 square yards; and from the humus tanks, 1831 square yards.

The high-level works were designed for a dry-weather flow of 500,000 gallons but, by chlorination, a flow of 600,000 has been treated satisfactorily. Chlorine is added to the raw sewage in the form of bleaching powder. The sewage then passes through two detritus tanks of 5000 gallon capacity and from thence through two Dortmund tanks, for primary settling. The effluent from these tanks passes through an aeration channel 4 feet wide and 4 feet 2 inches deep, so arranged that the sewage travels a distance of approximately three-quarters of a mile before coming back to the point of introduction. The effluent from the aeration tank is settled in three humus tanks, each with a capacity of 35,000 gallons.

The average analyses of the effluents from the high- and the low-level works are given in the table below. Figures are in parts per million.

	High-Level Works	Low-Level Works
Oxygen absorption (4 hours)	12.7	11.9
Nitric nitrogen	19.3	2.06
Total suspended solids	15.2	12.3

The sewage treated at the high-level works amounted to 18.14 gallons per capita sewered and had an oxygen-absorption figure of 141.0 p. p. m. At the low-level works the sewage treated was 19 gallons per capita and had an oxygen-absorption figure of 125.1 p. p. m.

Irlam Treatment Works—Lancashire

The Surveyor, **70**, 11 (July 3, 1931)

ABSTRACTED BY DOROTHY W. HARDT

Irlam and Cadishead, before the War, had a population of 7000 but industry has since raised it to 12,300, resulting in an average dry-weather sewage flow of 480,000 gallons per day.

Detritus tanks, precipitation tanks and percolating filters were suggested in 1915, to replace the original land-filtration treatment; but because of the War they were not again considered until 1922, when the Council adopted the activated-sludge process of sewage treatment by air diffusion. A plant was constructed at a cost of about $85,000 and further improvements were made on it in 1929, at a cost of about $50,000.

The sewage, made up of domestic refuse and a variety of industrial wastes which do not interfere with the working of the process, reaches the plant by gravity through an outfall sewer 3 feet in diameter. It passes first into two 4000-gallon detritus tanks, with hopper bottoms and bucket elevators for detritus removal. A 4-inch vertical pump permits discharge either into the main sewer or the sludge lagoon. Screens, 9 feet by 7 feet with $^5/_8$-inch spaces between bars, cover the outlets, from which screenings are removed by mechanical rakes driven by a $6^1/_2$-horse-power electric motor. (All electric power is generated at the plant.) A small tank equipped with diffusers preaerates the sewage on its way to the two 21,000-gallon preliminary-settling tanks, which work in parallel and have a detention period of more than two hours. These can be short-circuited if desired.

The sewage next passes into a mixing chamber, from which it is distributed to the three aeration units, arranged for spiral flow, with diffusers 1 foot from the walls of the tanks. The three aeration tanks have a capacity

of 380,000 gallons (about 9 hours' flow). The 230 diffusers pass 500 cubic feet of air per minute at a pressure of $4^5/_8$ pounds per square inch.

The four final-settling tanks, in the form of inverted pyramids 18 feet square and 20 feet to the apex, have a total capacity of 93,000 gallons. Sewage enters them through plain wooden guard boxes at the center of each tank. Sludge settles on the tapered walls and falls to the base, where it is pumped back to the mixing chamber to be combined with incoming sewage.

A small tank near the two 7700-gallon storm-water tanks, which receive all sewage—about three times the dry-weather flow (separated by a weir in the main channel)—before it passes to the river, receives excess sludge and conveys it to the sludge lagoons. Excess activated and sedimentation sludges are pumped to a lagoon and from there to drying beds.

The sludge is easily handled and dries rapidly. The final effluent flows over the edges of steel channels to a recorder chamber and is finally received by the River Glaze and the Manchester Ship Canal. Both dried sludge and screenings are in demand as fertilizer.

Photographs and a diagram accompany the report.

Reconstruction of Sewage Disposal Works—Sowerby Bridge, Yorks

BY J. NORMANTON

The Surveyor, 79, 459 (April 24, 1931)

ABSTRACTED BY G. P. EDWARDS

The new activated-sludge treatment plant at Sowerby Bridge, Yorks, completed in June, 1929, was designed to treat a dry-weather flow of 432,000 gallons per day and to give complete treatment to three times this amount in times of storm. Sewage flows through two grit chambers, each 10 feet by 6 feet, with an average depth of 5 feet, which are followed by two fixed bar screens with $^1/_2$-inch spaces. After passing through the screens, the sewage enters either of two settling tanks with a combined capacity of 72,500 gallons, which is approximately four hours' dry-weather flow. There are two groups of Simplex aeration pockets, each group being 90 feet long, 30 feet wide and 11 feet 3 inches deep and containing three aeration pockets 30 feet square. The total capacity of the aeration tanks is about 298,000 gallons, being approximately equal to sixteen hours of dry-weather flow. The final-settling tanks are constructed on the "Dortmund" principle and are arranged in two groups of six pockets, each pocket being 15 feet square by 16 feet deep, having a combined capacity of 158,000 gallons, equal to nearly nine hours' dry-weather flow.

The final effluent is discharged into the river Calder. Part of the settled sludge is returned to the aeration tanks and the excess may be pumped to the drying beds or to the main sewer above the grit chamber, where it mixed with the crude sewage and settles in the preliminary-settling tanks. This settled sludge is denser than that from the final-settling tanks and eases the work of the drying beds. Old contact beds were adapted for use as sludge drying beds.

Sewage Disposal at Hale, Cheshire

BY J. E. EVANS

The Surveyor, **79**, 585 (May 29, 1931)

ABSTRACTED BY G. P. EDWARDS

The Hale sewage works, opened in July, 1926, was among the earliest in England wholly designed and built on the activated-sludge principle. The sewage, about 390,000 gallons per day dry-weather flow from a population of 9000, is entirely domestic. The plant cost about $126,000. The sewage flows through preliminary-settling tanks, screens and two detritus tanks, working in parallel, with a combined capacity of 10,800 gallons. From the detritus tanks, the sewage passes into a mixing chamber where it is intimately mixed with return sludge by aeration. The mixture flows into four aeration units each consisting of three tanks which are 30 feet long, 5 feet 7 inches wide and 9 feet deep. Each tank is divided into three compartments by baffle walls in which there are small rectangular openings immediately over the diffusers and near the floor of the tank. Each unit contains thirty-one plate-type diffusers. The total capacity of the four units is 125,000 gallons, the dry-weather aeration period being about six hours. The liquid then passes to two settling tanks which have a total capacity of about 79,000 gallons and provide a four-hour settling period. The effluent flows to the river Bollin. Part of the settled sludge goes to two reaeration tanks with a combined capacity of about 31,000 gallons, after which it is returned to the mixing chamber. The excess sludge is again settled. The supernatant liquor is conveyed onto land where it percolates through into drains and then into the river. The settled sludge is drawn once a week with the preliminary sludge to lagoons for preliminary digestion. The primary digested sludge is dried on beds having an area of 1000 square yards. Grit is removed weekly and dried on the beds.

Exeter's New Sewage Purification Works

BY E. J. SILCOCK

The Surveyor, **79**, 603 (June 5, 1931)

ABSTRACTED BY G. P. EDWARDS

Exeter's new sewage purification works will consist of a detritus and three screening tanks with a total capacity of 90,000 gallons. The tanks are provided with coarse screens followed by fine screens fitted with power-driven rakes. The grit will be removed by an electrically driven traveling grab-dredger. The sewage, including storm water, after passing through the detritus tanks, will receive preliminary settlement in sixteen square hopper-bottomed settling tanks with a total capacity of 1,000,000 gallons, which is equivalent to eight hours' storage of the dry-weather flow. The tank effluent, together with storm water up to a total volume of three times the dry-weather flow, will pass to the Simplex aeration tanks, consisting of eight units with five pockets in each unit and having a total capacity of 2,020,000 gallons, which is equivalent to sixteen hours' detention on the basis of the dry-weather flow. The effluent will be settled in eight tanks, each containing two pockets and having a total capacity of about 780,000 gallons. The final effluent will be discharged into the river Exe. Part of the settled sludge will be returned to the aeration tanks and the surplus will either be pumped back into the raw sewage at the grit chambers, or to sludge-drying beds. The sludge-drying beds are constructed of clinker and fine ash on concrete slabs and are underdrained. The beds consist of 127 units with a total area of 20,000 square yards. The liquid drained from the beds will be pumped back into the raw sewage for retreatment. The estimated dry-weather flow is about 3,000,000 gallons. The estimated cost of the works is about $700,000 of which about $300,000 will be for sewers and $400,000 for the purification works, including the cost of the land.

The Activated Sludge Process in South Africa (Cape Town Experimental Plant)

BY E. H. CROGHAN

The Surveyor, **69**, 520 (May 8, 1931)

ABSTRACTED BY DOROTHY W. HARDT

In May, 1930, an experimental activated-sludge plant of the spiral-circulation type, designed to receive 24,000 gallons of pre-sedimented sewage daily, was completed at the sewage works of the southern suburbs of

Cape Town, at a cost of about $5000. This is one of the two experimental units now existing in the Union of South Africa, the other being a 2000-gallon daily capacity Simplex surface-aeration plant at Pretoria. The only activated-sludge working plants in use in that territory are three small ones under government departmental control and installed for isolated institutions.

By October, 1930, good oxidation of the sewage (which is municipal, septic and high in chloride content, not greatly influenced by industrial wastes) was secured and the effluent had 2.6 parts per million ammoniacal nitrogen and 17 p. p. m. nitric nitrogen. Results indicated that a minimum of 1.5 and a maximum of 2.5 cubic feet of air per gallon of sewage were required. The dried activated sludge was typical; it showed a high nitrogen content of 6.3 per cent and a good phosphoric oxide content of 3.4 per cent.

Careful records of operating costs are being kept for comparison with the trickling-filter, brushwood system in use at the local plants. At this early stage, however, costs cannot be considered.

The Activated-Sludge System in India

Trial of Air Diffusion and Mechanical Agitation Systems: The Nagpur Experiments

BY G. B. WILLIAMS

The Surveyor, 69, 627 (June 12, 1931)

ABSTRACTED BY DOROTHY W. HARDT

In 1926, Mr. Barnsby Williams, then Chief Engineer of the Public Health Department of the Bengal Government, was instructed by the Nagpur Municipal Committee to inspect their sewage disposal system and, as a result, the Simplex bio-aeration process, the activated-sludge system and septic-tank treatment have since been tried. The experimental plants completed in December, 1928, were designed to treat a dry-weather flow of 18,000 gallons per day. The problem at Nagpur is the disposal of sewage from an existing population of about 155,000 and a future population of 165,000, with a dry-weather flow of sewage of about 1,000,000 gallons per day from 80 per cent of the population.

Experimental Works.—Sewage was screened and passed through a long shallow detritus tank before reaching the inlets to the three installations.

The septic tank capacity was 11,000 gallons.

The activated-sludge plant consisted of four 4000-gallon aeration tanks, three of which were used for aeration and one for reactivation of sludge, returned by an air-lift pump. A Dortmund type sludge-settling tank

was provided with a Clifford inlet and a floating arm draw-off for the effluent. The rate of discharge was kept constant and independent of the rate of inflow.

The Simplex plant consisted of an agitating cone revolving in a 12,000-gallon square tank, with a bottom in the shape of an inverted pyramid, followed by a 5700-gallon sludge-settling tank with a deep pyramidal bottom. The effluent was discharged over a weir extending around all four sides, but there was no arrangement to compensate for the fluctuation of the rate of inflow.

Two sludge-drying beds of coir mats laid on brick foundations received the activated and the Simplex sludge.

Operation.—Both systems were started in January, 1929, and by February 25 satisfactory results were obtained. The strength of the sewage was found to be 7.6 gallons per capita. Details of operation are given in the following table:

Dates	Flow (G. p. d.)	Aeration, (Hrs. per Day)	Results
		Septic Tank Treatment	
Feb. 25 to April, 1929	(Operation delayed by needed repairs)		
April, 1929, and thereafter	8000 (Max.)		Considerable purification effected Best effluent for crops
		Activated-Sludge Plant	
Feb. 25 to middle of March, 1929	6000 (10-hr. day)	18	Satisfactory
Middle of March, 1929, to March, 1930	9000	12 (16% sludge present)	Sludge in good condition—settled rapidly
	15,000 (Some reduction was necessary due to clogged diffusers)		Brown, wormy sludge, easily dried, accompanied by loss of nitrogen—similar to "Simplex" sludge when dried
March, 1930, to May, 1930	16,000 (Further increase harmful)		Good results
May, 1930, to June, 1930	20,000 (Max.)	24 (Third aeration tank used as a reactivation tank)	Not as good as previous results
June, 1930	35,000 (Max.) (Oxygen absorption rose after rate of 24,000 was exceeded)		Average reduction of suspended solids to 1434 p. p. m. or less

Dates	Flow (G. p. d.)	Aeration (Hrs. per Day)	Results
		Simplex Bio-Aeration Process	
Feb. 25 to middle of March, 1929	6000 (10-hr. day)	18	Satisfactory
Middle of March, 1929, to March, 1930	(Operation temporarily stopped due to mechanical difficulties) 7000 (10-hr. day)	20	Satisfactory—gray, lifeless sludge, easily dried, accompanied by loss of nitrogen—similar to "activated" sludge when dried
March, 1930, to May, 1930	7000 (Unable to treat over 8000)		Successful treatment
May, 1930, to June, 1930	11,000 (Max.)	24	
June, 1930	14,000		Satisfactory

In June, 1930, all sewage was pre-settled in the septic tank for a period of 6.29 hours. Sludge was removed daily from the septic tank to prevent ebullition of gas. A firm scum was present in the tank. It was found that approximately 15 tons of sludge per diem could be obtained from a population of 140,000.

Lastly, return sludge from the Simplex plant was passed through the reactivation tank of the activated-sludge plant. With this procedure it was found possible to treat 35,000 gallons of settled sewage per day. The sludge showed an improvement and reached a standard previously set only by the activated-sludge plant.

Conclusions.—The author concludes that either system will be satisfactory at Nagpur but that, if the Simplex plant is chosen, the sludge must be reactivated. He also would recommend pre-settlement tanks, designed on the basis of one-half cubic foot per capita but so arranged that they could be extended to double this capacity. It is believed that construction and maintenance costs may eventually be entirely paid for by the sale of the valuable manure produced.

Discussion

Lancashire Members' Visit to Irlam: The Nagpur Experiment

The Surveyor, **70**, 12 (July 3, 1931)

An abstract of Mr. Williams' paper was read before the Lancashire members of the Association of Managers of Sewage Disposal Works on June 27, 1931, by Mr. F. C. Temple, Chief Town Engineer of Jamshedpur, India, and partner of Mr. Williams. Considerable discussion followed.

Dr. E. Ardern began by calling attention to the fact that the sewage in

India came from a different diet and water level and hence could not be compared with English sewage. He was surprised at the slight difference in costs of the aeration tanks for the activated-sludge plant and the Simplex system (approximately $36,550 for the former and $42,300 for the latter). Mr. Temple later answered Dr. Ardern by stating that the costs given in the paper were merely quotations from the individual firms and that they would probably differ somewhat more when recommendations were made.

Mr. J. Bolton could not quite understand why the Simplex plan which he had so successfully nurtured at Bury had shown up so badly at Nagpur; but, on further investigation of plans, he concluded that "short-circuiting" could largely be blamed. The inlet and outlet of the tank were but 15 feet apart and a portion of the sewage could easily pass through and escape the aerating cone entirely. This would explain the improved results after reactivation, as well as the gray color and slower settling rate of the Simplex sludge. Mr. Bolton mentioned the fact that reversing the direction of rotation of the cone had completely cured "short-circuiting" in other plants and would probably do so at Nagpur. (Mr. Temple agreed that "short-circuiting" probably had taken place.) Mr. Bolton felt that the costs of about $1350 per year for lubricating oil and stores and about $1350 for repairs to the Simplex plant, estimated in the paper, were extremely high; because he had experienced a cost of only $50 per year for a plant handling 75,000 g. p. d. He concluded that data on a faultily designed small plant were unreliable.

Mr. W. Scott blamed the failure of the Simplex plant to produce better results upon inexperienced operation, and backed up his statement with the quotations, "it is, however, to be supposed that this difficulty in reactivating the installation was due primarily to some septic sludge having lodged in some part of the installation, where it remained a constant source of infection."

Mr. Scott seemed much concerned about the bulking of the sludge, which was reported particularly in connection with the Simplex sludge. He said that bulking sludge was generally experienced at Bury, where a well-clarified effluent was nevertheless produced, while Mr. Temple found that Simplex sludge which had deteriorated and bulked was extremely difficult to get back into condition, without emptying the tank and beginning anew. Mr. Scott wanted to know to what Mr. Temple attributed the bulking and said that he would take exception to under-aeration or sludge "out of condition" as the explanation. He also wondered if the aerated activated sludge ever bulked. (Mr. Temple stated that bulking in India assumed very large proportions, occurring oftener than once a week, and that he had actually seen sludge bulk within three minutes, a whole settling tank becoming a mass of spongy sludge. However, he had

cured bulking by speeding up the return sludge-lift immediately, sometimes doubling the velocity of sewage flowing through the aeration tanks.)

Mr. Scott objected to the comparison of settling rates of a slow-settling, poorly activated Simplex sludge with a well-activated sludge, because the former was obviously "out of condition" and hence not to be compared with the latter

Mr. W. T. Lockett, the chairman, closed the discussion by calling attention to the fact that, since the experiments showed that bulking occurred less frequently in the diffused-air system than in the activated-sludge process, when other conditions were the same, it was not due to thread growth but to a "failure to meet the fundamental requirements of the process in some particular regarding aeration."

Rivers Pollution Prevention in the West Riding of Yorkshire

The Surveyor, 79, 565–566 (May 22, 1931)

ABSTRACTED BY C. T. CARNAHAN

The report of the Rivers Board in the West Riding of Yorkshire for the past year shows that a great improvement has been taking place in the efficiency of sewage purification works and their management during the past decade. Management is least efficient in those rural districts which include a large number of small plants, and where these individual plants are under the control of part-time unskilled operators. It is recommended that in such cases a competent manager should be appointed to supervise all of the works in the entire district.

The board also recommended the treatment of wastes from pit-head baths or the connection of such baths to public sewers where available. Analyses of waste samples from these sources show them to be equivalent in strength to the sewage of many residential towns and they are a source of river pollution. The waste waters come from two sources, soapy water from the bath and wash water from flushing the floors after use by each shift. The average volume of wastes is about 10 gal. per capita and is discharged at intervals so that equalization tanks are necessary where separate treatment is required.

About two-thirds of the 2000 trade premises in the West Riding are connected to sewers and the remainder have their own treatment works. Special attention is being given to the treatment of certain solvents used in scouring processes and present in some of the textile effluents.

The report also deals with conditions in the main catchment area of the West Riding, and gives a résumé of conditions at each of the county sewage works.

Sewage Treatment by Dilution

BY E. J. GOODACRE

The Surveyor, 79, 468 (Apr. 24, 1931)

ABSTRACTED BY C. T. CARNAHAN

About 90 per cent of the towns along the English coast discharge crude sewage into the sea; and it is a matter of common experience that sewage discharged into tidal waters has no harmful effect either to the water or to fish life, provided that screening or sedimentation has taken place prior to discharge.

The various Royal Sewage Commissions have given attention to this question from time to time.

Much valuable work has been done on the question of sewage purification by dilution in studies for the New York Sewerage Commission, of the aeration of the waters of New York Harbor, which are not entirely deoxygenated even after the discharge of 800 m. g. d. of crude sewage into them. It must be remembered that sea water will hold only about four-fifths the amount of oxygen when saturated as fresh water will under similar conditions (60° F.). The amount of oxygen is, however, sufficient for oxidation of the sewage, especially if the solids have been removed and trade wastes are not present. Sewage discharged into the sea is consumed by the joint action of various forms of microscopic and macroscopic organisms which live in these surroundings.

Considerable research work has been done along this line by Dr. W. E. Adeney who made a series of experiments showing the fermentive changes undergone by sewage matter in true solution and in the colloidal state when discharged into fresh and sea water. The results show that the organic matter undergoes two distinct stages of oxidation. The first stage results from the action of saprophytic bacteria in the presence of excess dissolved oxygen, during which the harmful organic matter is converted into carbon dioxide, ammonia and water and some simpler organic compounds. The second stage is due to the action of nitrifying bacteria in the presence of excess dissolved oxygen, during which the ammonia and lesser organic compounds formed in the first stage and the ammonia originally present in the sewage are converted to carbon dioxide and nitrates. Much depends upon the replenishment of oxygen in the sea water to meet the oxygen demand of the sewage.

The removal of floating and visible solids is essential and this is done in many places by means of screens or settling tanks. In some locations where screening plants cannot be erected, the solids are broken up into minute fragments by means of a sewage disintegrator.

Although the removal of visible solids and the subsequent purification

of sewage by dilution in sea water is satisfactory under normal conditions, the popularity of bathing demands additional safeguards against disease-carrying bacteria.

The use of chlorine as a safeguard against disease-carrying bacteria and as a means for reducing odors and the B. O. D. of sewage before discharge into the sea, has been studied at length, especially in America. The maintenance cost for chlorine treatment is reasonable and its operation has become easier lately, owing to the use of larger containers. The results of chlorine treatment appear to be satisfactory.

Laboratory Studies of Sludge Digestion

BY A. M. BUSWELL AND S. L. NEAVE

Illinois State Water Survey, *Bulletin* **30**, 84 pp. (1930)

ABSTRACTED BY H. GLADYS SWOPE

Introduction.—Normal sludge digestion involves the liquefying and hydrolyzing of the insoluble proteins to soluble split products, some of which are resynthesized into living cells.

Biochemical Changes in Nitrogenous Matter.—The primary nitrogenous material in domestic sewage is partially decomposed by chemical or biochemical changes before reaching the treatment plant. The largest source of nitrogen of human origin is from urea (35 per cent) and from bacterial protein (6 to 7 per cent) in feces. The nitrogenous wastes yield ammonia, free amino acids and amines as secondary products.

A comparison of several samples of freshly settled solids in Imhoff tanks and separate sludge-digestion units was made and in so far as nitrogen transformations were concerned the best criterion of the completeness of sludge digestion is the decrease of purine nitrogen.

Biochemical Changes in Carbonaceous Matter.—As gas yields are of major importance, observations were made on a number of pure compounds added to well-digested sludge to determine the amount of gas produced.

Sewage grease, which is a mixture of the glycerides and soaps of the higher fatty acids, produced large amounts of gas. In acid media (pH 5.0–5.5) gas production was roughly proportional to the grease content of the solids fed, a scum containing 73 per cent grease producing the most gas. Approximately 75 per cent of the added grease was destroyed in four weeks, 50 per cent being recovered as gas and the other 25 per cent as volatile acids (mainly acetic).

Large-scale experiments (8-liter reaction vessel) were made to determine more accurately the degradation of the fatty acids. In one

run using acetic acid (total of 159.69 gr.) there remained at the end of 35 days, 45.51 gr., or 114.18 gr. decomposed. This amount should yield 30.5 grams of methane and 83.7 grams of carbon dioxide. Methane actually produced was 28.1 grams or 92.9 per cent of theoretical and 79.2 grams of carbon dioxide or 94.7 per cent theoretical. Acetic acid digests according to the equation:

$$C_2H_4O_2 \longrightarrow CO_2 + CH_4$$

A run using propionic acid gave the following results: propionic acid metabolized, 130.1 grams; methane produced, 48.6 grams (98.7 per cent of theoretical); carbon dioxide produced, 96.3 grams (99.6 per cent of theoretical); hydrogen produced, 0.24 gram. Propionic acid digests according to the following:

$$4C_3H_6O_2 + 2H_2O \longrightarrow 5CO_2 + 7CH_4$$

The carbon dioxide to methane ratio actually found from the above experiment was 5.05:7.

Mechanism of Anaerobic Oxidations.—A review of the literature is presented and experimental evidence is given for the mechanism of the fatty acid degradation.

Theoretically, 130 grams of propionic acid could yield 77.3 grams of carbon dioxide but actually the yield was 96.3 grams. The 19 grams excess carbon dioxide represents 13.8 grams of oxygen, which must have come from the water. The mechanism by which some carbon atoms accept hydrogen to give methane explains the experimental gas ratios. The number of molecules of water required by one molecule of fatty acid is $\left(\frac{n-2}{2}\right)$ where n is the number of carbon atoms in the acid. The general equation for the anaerobic oxidation of the saturated monocarboxylic acids is:

$$C_nH_{2n}O_2 + \left(\frac{n-2}{2}\right)H_2O \longrightarrow \left(\frac{n+2}{4}\right)CO_2 + \left(\frac{3n-2}{4}\right)CH_4$$

The complex values of $\frac{CO_2}{CH_4}$ ratios instead of the simple 1:1 is due to two superfluous hydrogen atoms in water when acting as an oxidizing agent.

Propionic acid gives this ratio as 5:7 and the α-hydroxypropionic acid (lactic acid) should give 1:1. Experimentally this is the case.

The last section of the *Bulletin* is devoted to the analytical procedures used and to an extensive bibliography.

Studies on Two-Stage Sludge Digestion

BY A. M. BUSWELL

Illinois State Water Survey, *Bull.* **29**, 92 pp. (1928–29)

ABSTRACTED BY H. GLADYS SWOPE

Introduction.—Semi-plant scale operations on two-stage digestion were started in January, 1928, in order to verify laboratory results. The digestion of sewage solids occurs in two stages, the acid stage followed by the inoffensive or alkaline stage. Under normal operation these two stages occur simultaneously and tend to neutralize each other or another explanation is that the fatty acids are decomposed into CH_4 and CO_2 as soon as they form. The degree of decomposition of the solid was also studied.

The experimental plant consisted of a nidus sedimentation tank (3 hours detention period), a primary (2000 gal.) and a secondary (1560 gal.) digestion tank.

The first trouble experienced was the building up of a scum, 26 inches thick, in a month. This difficulty was eliminated by recirculation of the sludge liquor. The foam problem next presented itself and this was also eliminated by recirculation.

Plant Design and Operation.—The digestion tanks were of wood-stave construction with hoppered concrete bottoms. The primary tank was 7 feet 7 inches in diameter and 9 feet 10 inches deep to the bottom of the cone. The secondary tank was 7 feet 6 inches in diameter and 5 feet deep. Both tanks were provided with overflow valves just above the center for removal of liquor when additions to the tank were made and opposite these valves were inlet valves put below the center for sludge additions. The tanks were also provided with steam heating coils so as to maintain a temperature of 25° C. Each tank was covered with a metal hood for gas collection. Sludge was pumped from the primary to the secondary tank.

The fresh sewage sludge used for feeding the primary tank was obtained from a nidus settling tank. The nidus tank was fed with sewage approximating a proportional relation to the volume and concentration of the wastes in the sewer by adjusting the feed every eight hours.

Scum thickness was measured.

The sludge pumped to the secondary tank was determined from the volume of liquid displaced from the secondary tank.

Solids Balance.—Samples of sludge and overflow liquors were composited for each day according to flow. The following analyses were made: total solids, alkalinity, ammonia nitrogen, total nitrogen, pH, volatile acids, settling solids, volatile matter and ash, mineral oil, and sludge drainability.

The fresh sludge averaged a pH of 6.4 and 2.89% solids over the period from June 16, 1928–January 11, 1929.

For this same period the following average analyses were obtained on the primary tank overflow and secondary tank overflow, respectively: Temperature, 23.9° and 23.5° C.; total solids (as determined) 2300 and 1760 p. p. m; settling solids, 605 and 185 p. p. m; alkalinity 1775 and 1979 p. p. m; ammonia nitrogen, 250 and 282 p. p. m; pH, 7.1 and 7.3.

The transferred sludge showed the following: 5.06% solids, 2030 p. p. m. alkalinity, 340 p. p. m. ammonia nitrogen, 1850 total nitrogen, pH 7.1, and 232 p. p. m of volatile acids.

It was found that the alkalinity of the secondary overflow samples was higher than the total solids; therefore, volatile material must be lost during drying. The volatile material is ammonium acetate and carbonate, the latter being decomposed at a temperature of 80–85° C. The corrected total solids were computed by adding to the total solids determined, ammonium acetate and carbonate present.

The dehydration taking place was obtained by subtracting from the total solids digested the gas obtained and sulphate digested.

Sludge drainability tests were made by pouring a liter of sludge on 3/4 inch of wet sand in a 28-mesh sieve. The amount remaining, in per cent of the total drained, was plotted against time intervals.

The following table summarizes the results of the experiment:

Material	Added, Pounds	Residue, Pounds	Digested, Pounds	Produced, Pounds	Liberated, Pounds	Liquefied, Pounds	Digestion, Per Cent	Liquefaction, Per Cent
Total solids	2305.0	858.8	1446.2	...	..	.....	62.6	..
Settling solids	2250.0	567.6	.....	...	..	1682.4	..	74.8
Protein	308.0	112.3	195.7	...	..	.....	63.5	..
Sulphate	90.0	15.0	75.0	...	..	.....	83.0	..
Dehydration	.....	...	169.2	...	..	.....	..	..
Ammonium compounds	24.5	130.9	.....	106.4	..	.....	..	..
Total nitrogen	75.1	55.3	.....	...	19.8	.....	..	..

Gas, Grease and Cellulose Balance.—The composition of gas liberated from sewage sludge generally varies from 65–90% methane, 5–35% carbon dioxide, 0–10% hydrogen and 0–8% nitrogen. The average analyses of gas produced in this experiment over the period of June 20, 1928, to January 17, 1929, follows:

RESULTS EXPRESSED IN PER CENT[1]

	Primary Tank					Secondary Tank				
	CO_2	H_2	CH_4	N_2[2]	Air[2]	CO_2	H_2	CH_4	N_2[2]	Air[2]
Max.	34.8	7.5	71.9	35	16.0	33.1	7.7	75.0	23.0	24.0
Min.	17.6	0.1	41.1	0	0.0	17.8	0.0	57.4	0.4	0.0
Avg.	29.5	3.4	66.9	4.3	(2.2)	28.3	3.7	68.0	4.9	(2.3)

[1] Calculated to an air-free basis.

[2] By difference.

[3] The oxygen determined was multiplied by five and reported as air.

The average gas produced (CH_4, H_2 and CO_2 at std. cond.) during this same period was 15,238 cu. ft. in the primary tank and 1941 cu. ft. in the secondary tank.

The relation between gas production and total solids added to the system is as follows:

	Cubic Feet
Gas produced per pound of solids added[1]	7.7
Gas produced per pound of solids digested[1]	12.1
Gas produced per capita per day[2]	0.39
Gas produced per capita per day—primary	0.34
Gas produced per capita per day—secondary	0.05

[1] These figures include dissolved and bicarbonate CO_2 and are corrected to an air- and nitrogen-free basis.

[2] Same as (1) except does not include the dissolved and bicarbonate CO_2.

Almost 89% of the total gas was produced in the primary tank.

In acid digestion, and also in alkaline digestion, a rapid destruction of grease and calcium soaps occurred, with the production of the lower fatty acids, some of which ferment further to give methane. The rate of digestion as measured by gas production is roughly proportional to the grease content of the solids.

The Use of Digestion Tank Liquor instead of Sludge for Seeding.—In order to determine the value of seeding sludge with supernatant liquor, experiments were made by comparing the digestion in a seeded tank with two separate runs on an unseeded tank. At the same time data were collected on lagooning.

Gasification in a liquor-seeded tank started immediately and normal digestion was reached in 18 days. In the unseeded tanks gasification did not start appreciably until after 25 days and normal digestion was not reached until the 40th day.

Primary tank sludge of 4.4% solids was removed each week to a lagoon where it was concentrated to 9.7% solids. The drainability of the primary sludge improved as digestion improved. Sludge from the lagoon had the same draining characteristics as the primary sludge, but the lagooned sludge had double the solids content of the primary sludge. The lagooned sludge had all appearances of a well-digested sludge and its odor, texture and appearance were comparable to secondary digestion tank sludge.

New Method for Determination of Settling Solids.—Due to the inaccuracy of the Gooch crucible method for the determination of suspended solids in raw sewage a new method known as "settling solids" determination was devised. The method consists of putting a liter of the sample in a vertical 3-foot glass tube $1^3/_4$ inch in diameter, closed at the lower end by a rubber stopper. Solids settle for 2 hours. About 950 cc. of the supernatant liquor is siphoned off and the residue is drawn off through the lower end of the glass tube, measured and poured into an evaporating dish.

The liquor is evaporated on a steam bath and the solids weighed. A correction is made for the dissolved and non-settling solids contained in the liquor.

Survey and Report of River and Stream Conditions in the State of Maine

BY CHARLES L. WALKER, SANITARY ENGINEER*

REVIEWED BY E. HURWITZ

A survey of the principal streams in Maine was undertaken during the summer of 1930, by the paper and pulp mills, to ascertain the condition of the water in these streams and to determine the effect of paper and pulp mill effluents on the rivers.

Sampling stations were located on the St. Croix, Penobscot, Kennebec, Androscoggin and Presumpscot rivers. In all there were 69 sampling points, so placed as to indicate the effect of the mill wastes on the stream. The work was done in 1930 during an unusually dry season and the stream flows were consequently lower than normally prevail but not the lowest on record. B. O. D. tests were made on the wastes discharged into the stream by the mills. A table showing the types of wastes and their 1- and 5-day B. O. D.'s are given below:

Waste	B. O. D., 1-day	B. O. D., 5-day
Sulphite liquor	1200 p. p. m.	6700 p. p. m.
Pulp-mill waste	300 p. p. m.	950 p. p. m.
Paper-mill waste	15 p. p. m.	75 p. p. m.
Weak black liquor	90 p. p. m.	500 p. p. m.
Fibre board	1.5 p. p. m.	6.8 p. p. m.
Lime sludge, per 1000 lbs. (dry)	1.2 lbs.	5.2 lbs.
Black ash, per 1000 lbs. (dry)	1.8 lbs.	4.3 lbs.
Ground wood tailing per 1000 lbs. (dry)	3.0 lbs.	12.0 lbs.

In determining dissolved oxygen the use of the alkaline hypochlorite method of Theriault was made necessary by the presence of sulphites. The procedure is: Add sufficient hypochlorite solution to oxidize the reducing substances; mix well for about 20 seconds; acidify with 1 cc. of a 10 per cent solution of H_2SO_4; add KI to release the iodine; and finally neutralize with $N/10$ sodium sulphite using starch as an inside indicator. Then manganous sulphate and a slight excess of alkaline KI is added and the procedure continued as in the Winkler method.

The dilution water used in these B. O. D. tests was distilled water buffered with 300 p. p. m. sodium bicarbonate, as recommended by the Committee of the Ohio and Great Lakes Boards of Public Health Engineers.

The survey showed conditions on the St. Croix River to be satisfactory

* Cornell University, Ithaca, New York.

at all points. At none of the stations did the dissolved oxygen fall below 3 p. p. m., considered to be the minimum concentration, where fish life is involved. During the testing period the minimum oxygen content was greater than 5 p. p. m.

In the Penobscot River, except for a stretch of about 5 miles on the lower West Branch, the oxygen content was always above 5 p. p. m. In this stretch the dissolved oxygen approached the critical 3 p. p. m. At the Bangor salmon pool the concentration never fell below 6.5 p. p. m.

Conditions in the Kennebec River were found to be good, with a minimum dissolved oxygen content of 5 p. p. m., except at South Gardiner. Here the amount approached 3 p. p. m. Indications are that any substantial increase in pollution of this river will produce unfavorable conditions at South Gardiner.

The dissolved oxygen content of the Androscoggin River was found to be above 3 p. p. m. at all points except that portion immediately below Lewiston and Auburn. The margin of safety in this river is less than in any of the others studied, due to the fact that it receives a large quantity of both industrial and domestic wastes in the state of New Hampshire, before they reach Maine. Reaeration, due to frequent and pronounced falls, enables the river to handle this pollution satisfactorily. In the 4-mile stretch between Lewiston and Auburn the dissolved oxygen fell to 2 p. p. m. Except for this stretch the oxygen rapidly increases by reaeration.

The dissolved-oxygen content of the Presumpscot River gradually diminishes down stream, but remains above 3 p. p. m. Any substantial increase in pollution load on this stream will create undesirable conditions. The tendency, however, is toward a reduction of the pollution load.

The results of tests made of the different mill wastes indicated that the oxygen demand of the different pulp and paper mills ranges from a fraction of 1 per cent to 10 per cent of the oxygen available in the stream water.

The report gives a detailed account of the condition of each river and the effect of the wastes from the mills along the river course. It includes, also, the results of some bacteriological and plankton studies.

The Operation of a Municipal Plant Handling Only Domestic Sewage

BY A. J. FOOTE

The American City, **45**, 97–101 (July, 1931)

ABSTRACTED BY E. HURWITZ

The sewage disposal plant at Mamaroneck, New York, is unique in that it treats entirely domestic waste, no industrial waste of any sort reaching the plant. The original installation was designed for a population of 3000

and consisted of bar screens, a screen chamber with two sedimentation tanks, a chlorine-mixing chamber, three hydrolyzation tanks and a pump house equipped with one 450 g. p. m. sludge pump. The plant effluent discharges into Long Island Sound about 1000 feet from the nearest land, through a 12-inch cast-iron outfall sewer.

Since the original installation, the population has doubled and several additions have been made to the plant. A second set of sedimentation tanks has been added, together with a grit chamber. A sludge digestion tank with Downes floating cover, and two glass-covered drying beds, have been installed. The original hydrolyzation tanks have been converted into sludge storage tanks and the sludge-pumping facilities have been increased.

The sewage is delivered to the plant by low lift pumps and then travels by gravity through the grit chamber and $1^1/_4$-inch bar screens to the sedimentation basins, which have a detention period of three hours. The effluent then passes over a weir to the chlorine-mixing chamber and from there into the outfall sewer.

Sludge is pumped daily from the sedimentation tanks to the digestion tank, accumulating at the rate of 300 cubic feet every four days. The digestion tank has a capacity of 18,000 cubic feet. The digestion period averages 60 days. No trouble has been experienced due to acid sludge, the pH remaining constant at 7.0 to 7.2. The gas yield for 1930 averages 2400 cubic feet per day and is used to maintain the temperature of the tank at 78° F. the year round, and for heating the sludge-pumping and chlorine house.

Recirculation of sludge was tried, with doubtful results, the only noticeable effect being the tendency to prevent packing of sludge at the bottom of the tank.

The digested sludge is pumped on the beds to a thickness of about six inches. The time required to dry the sludge to a condition where it can be ground was found to be 15 days in the winter months. It is expected that this time will be materially reduced during warm weather. The sludge is being taken away as fertilizer but no income is at present derived from it.

Twenty Years Ago and Today—Modernizing a Sewage Treatment Plant

BY THOMAS F. BOWE

The American City, **44**, 91–94 (May, 1931)

ABSTRACTED BY E. HURWITZ

Increased and irregular flow to the treatment works at Washington, New Jersey, made necessary the reconstruction and enlargement of this plant to provide for the extra burden. The primary treatment units of the

old plant consisted of a septic tank with a capacity of 150,000 g. p. d. and an Imhoff tank with 155,000 gallon capacity. The secondary treatment units consisted of contact beds discharging directly to sand filters with an estimated capacity of 190,000 g. p. d. and adequate open sludge-drying beds.

In planning and constructing the new plant, efficient use was made of all the original units. The Imhoff tank was retained in service with only slight alterations and a new hopper-bottomed settling tank consisting of two compartments of three hoppers each was built to give additional settling capacity. Sludge was removed by gravity to the detritus compartment of the original septic tank, now used as a sludge-inspection well. It was then pumped from this well into either or both compartments of the septic tank, now used for separate sludge digestion. The tank was altered so that sludge can be drawn into the inspection well and thence discharged into the upper portion of the digestion tanks. It is anticipated that this circulation will increase the efficiency of the tanks and expedite the formation of a well-digested sludge of small water content.

The effluent from the Imhoff tank can be treated on either the old sand filters or the new trickling filters. The effluent from the new settling tanks is treated on the trickling filters. The dosing tank for this filter is designed so that despite the variable flow to the plant, the sewage is applied to the filter in doses of equal volume and is spread evenly over the stone. Chlorine for odor control is applied at the dosing tank.

A new grit and screen chamber, consisting of two compartments designed to maintain a velocity of one foot per second, was built. The old sludge-drying beds, which were entirely adequate, were enclosed in a glass superstructure to permit a regular schedule of drying regardless of weather conditions.

The new plant has a capacity of 400,000 g. p. d. It has been in operation since September, 1930. An immediate improvement was noted in the condition of the stream receiving the effluent. Ninety-eight per cent removal of settleable solids is effected and the plant effluent is entirely satisfactory to the State Board of Health.

How Dunkirk Cleaned Up Its Front Yard

BY FREDERICK M. WING

The American City, **44**, 130–132 (May, 1931)

ABSTRACTED BY E. HURWITZ

A campaign for improvement on the lake front started by the Chamber of Commerce and the local newspaper of Dunkirk, New York, resulted in

the building up of a new sea wall, a sewage treatment plant, and a new sewer to intercept the sewage which formerly emptied into Lake Erie, causing unsightly and unsanitary conditions along the lake front.

The disposal plant is designed to serve a population of 30,000 people with an estimated flow of 150 g. p. d. per capita. The maximum rate to be treated is 4.5 m. g. d. The sewage flows first through a one-inch mechanically cleaned bar screen, and then through a 16-foot square Dorr detritor. From the detritor it flows into a well and is lifted 48 feet by pumps, into two Imhoff tanks. These tanks have a detention period of 2.5 hours and a sludge capacity of 3 cubic feet per capita. They are designed so that the flow may be reversed. Adequate provision is made to facilitate scum removal and cleaning of tanks.

The effluent from the Imhoff tanks flows into the final-settling tank. This tank has a detention period of one hour. The effluent is chlorinated as it enters this tank, a residual of 0.2 to 0.5 p. p. m. chlorine being maintained. The final effluent then flows through a cast-iron outfall sewer emptying into the lake about a quarter of a mile from the shore.

The sludge is pumped from the Imhoff tanks and final-settling tanks onto glass-covered drying beds with an area of about 27,000 square feet, based on an estimated requirement of 0.6 sq. ft. per capita. The dried sludge is removed from the beds by hand into overhead carriers and dumped into trucks to be carted away.

Status of Pea-Canning Waste Treatment

BY A. E. KIMBERLY

Water Works and Sewerage, **78**, 126–128 (May, 1931)

ABSTRACTED BY C. T. WRIGHT

The wastes produced in packing peas comprise all the process water used at the factory, carrying in suspension whole or broken peas and some pods and, in solution, organic matters of vegetable origin.

On the basis of a 2-line cannery, the Wisconsin studies show that the total volume of waste which requires treatment is about 100,000 gallons daily, produced at a rate of about 140 gallons per minute. The average waste from pea-canning is acid to phenolphthalein, averaging about 300 parts per million acidity, with pH of 4.9 and a 5-day B. O. D. of about 1300 p. p. m. The dilution required for a waste of this nature, to prevent nuisance and to conserve fish life, is at least 155 to 1.

For pea-canning wastes a revolving screen with wire cloth of 40 meshes per inch, having openings of 0.0160 inch, is very satisfactory and will remove about 80 cubic feet of screenings per 100,000 gallons of pea waste.

Each square foot of screen will handle about 200 gallons of pea waste per hour. The cost of a screening plant for a 2-line cannery is about $1200. The daily operating cost, including the disposal of screenings, is about $10.

The conclusions drawn during the tests in New York on the chemical precipitation of pea wastes are that the application of from 7 to 10 pounds of lime and from 3 to 5 pounds of ferrous sulphate, per 1000 gallons of waste, produces, with proper mixing, a readily settleable floc, effecting the removal of from 40 to 50 per cent of the 5-day B. O. D., and producing a practically clear effluent. The Wisconsin experiments indicate that, with the application of 7.25 pounds of lime and 3.25 pounds of ferrous sulphate per 1000 gallons of waste, the oxygen demand can be reduced approximately 75 per cent.

The coagulated wastes may be settled in 2 hours in continuous-flow tanks or in 1 hour in fill-and-draw tanks. The sludge volume is about 10 per cent of the volume of waste treated. The sludge dries rapidly if sufficient lime has been applied to produce a pH in excess of 10.0. Three thousand square feet of sludge bed area are required for each 100,000 gallons of waste per day, based upon a 7-day drying period and the application of sludge to a depth of 3 feet.

The cost of fill-and-draw plants is estimated at $5000 per 100,000 gallons of waste treated per 12-hour day and about $5500 on a continuous-flow basis.

The New York tests suggest final chlorination, with sufficient chlorine added to produce a residual of 0.5 p. p. m., requiring an initial dose of from 8 to 30 p. p. m. The tests show that chemical precipitation is sufficient only when the final dilution is not less than 25 to 1.

Pea wastes, properly screened, may be oxidized on trickling filters. When operated at the rate of 0.5 m. g. a./d., such filters remove from 80 to 95 per cent of the 5-day B. O. D. This treatment is adequate when the final dilution is not less than 5 to 1. Trickling filters operated at the rate of 2.0 m. g. a./d. remove from 50 to 70 per cent of the B. O. D., a reduction which is adequate when the final dilution is not less than 20 to 1.

A trickling-filter plant, including pumps and fine screens, with a capacity of 100,000 gallons per day, costs about $6000 under operation at 2.0 m. g. a./d. and about $20,000 under operation at 0.5 m. g. a./d. Operating costs are about $25 and $35 per day, respectively.

Trickling filters should be aged for 2 weeks with sewage before turning on the canning wastes.

The stack liquor obtained from the vines and pods after they have been stacked or placed in silos contains from 5 to 20 times as much organic matter as an average waste and should never be discharged into a stream. By the addition of 100 pounds of lime per 1000 gallons of liquor, it is possible

to effect a reduction of 83 per cent of the 5-day B. O. D., thus permitting this liquor to be treated with the main volume of plant wastes.

The sludge from chemical treatment has a fertilizing value of $3.50 per ton.

Controlling Sewage Plant Odors by Chlorination

BY R. L. PATTERSON

Municipal Sanitation, **2**, 6, 281 (June, 1931)

ABSTRACTED BY C. T. WRIGHT

Preceding the application of chlorine to control odors from the Imhoff tank, samples of the sewage were taken and the average amount of hydrogen sulphide determined. Samples were collected at various manholes, at pumping stations and at the plant. The average hydrogen sulphide content of the sewage at the upper manhole was 1.7 parts per million and it increased to 7.9 p. p. m. in the Imhoff tank effluent.

Chlorine was first applied to the sewage at one of the manholes to destroy the sulphide-splitting organisms before hydrogen sulphide was produced in large quantities. The average hydrogen sulphide content at this point was 4.0 p. p. m. The estimated flow at this point was 450,000 gallons per day. Using a chlorine dosage of 45 pounds per 24 hours, or 13.2 p. p. m., reduced the hydrogen sulphide content from an average of 6.5 p. p. m. to 4.6 p. p. m. in the equalizing basin of the Imhoff tank. Using a dosage of 100 pounds per 24 hours, or 30 p. p. m., reduced the hydrogen sulphide content to 2.8 p. p. m. in the equalizing basin. The odors at the Imhoff tank were reduced, but not sufficiently to prevent complaint.

To avoid using excessive quantities of chlorine, the point of application was moved from manhole No. 2 to the Imhoff tank, the chlorine being mixed with sewage in the pump pit. With a dosage of 70 pounds per 24 hours, or 11.7 p. p. m., the hydrogen sulphide in the equalizing basin was reduced from 6.5 to 1 p. p. m. and, in the effluent from the tank, from 7.9 to 2.0 p. p. m. By keeping down the hydrogen sulphide content to 1.5 p. p. m. or less, odors were noticeably controlled at the Imhoff tank and at the effluent discharge pipe.

Chlorination of Sewage

BY M. M. COHN

Municipal Sanitation, **2**, 270–275 (June, 1931)

ABSTRACTED BY C. T. WRIGHT

It is now generally reported that efficient disinfection of sewage may be consistently secured by the application of sufficient chlorine to produce a residual as low as 0.2 p. p. m. after a contact period of ten minutes or more. The application of chlorine for disinfection is most effective if carried out ahead of settling tanks rather than after sedimentation has taken place. When tank treatment alone is provided, the fresher condition of the unsettled liquor requires less chlorine to satisfy the demand.

Odors from settling tanks have been reduced by chlorination of the sewage just ahead of the tanks, at short distances above the tanks in the trunk sewer and, in several instances, several miles above the treatment plant. The present tendency is toward chlorination of the sewage before it becomes septic, in view of the saving in chlorine thus effected. The satisfaction of the entire chlorine demand of the treated sewage is unnecessary for the production of unobjectionable conditions and the presence of small amounts of hydrogen sulphide in the chlorinated flow is not troublesome. The application of chlorine to the sewage entering settling tanks has resulted in clarified effluents which can be sprayed on filters without the production of odors. Odors at the filters can be controlled by chlorination of the effluent from the dosing tanks.

The action of chlorine has been explained to have a stabilizing effect on the finely divided colloids and on the dissolved organic matters in sewage. These substances are subject to rapid fermentation in tanks, causing acid conditions and the retardation of gas production. The stabilizing effect of chlorination is assumed to be instrumental in increasing the rate of sludge digestion.

Pooling on the surface of trickling filters can be controlled by a heavy chlorination of the dosing tank effluent. The effect of this procedure is to destroy the organic gelatinous film on the stones, causing it to be sloughed off.

It has been reported that the B. O. D. of sewage plants effluents can be reduced 25 per cent, or more, by adding sufficient chlorine to give a residual of from 0.2 to 0.5 p. p. m. In addition, chlorination has a marked inhibitory effect upon biological activity in sewage for a short period after complete chlorination, thus giving the agencies of natural purification in the stream a chance to work before biological action is resumed.

To prevent the disintegration of concrete conduits and mortar joints at the water line in sewerage systems, chlorination of the crude sewage, ahead

of points of septicization, has proven effective. That this preventive measure also reduces odors from manholes and at the treatment works itself is an additional advantage.

At Barnsley, England, treatment of septic sewage with calcium hypochlorite has permitted the bio-aeration units to produce a stable effluent. Addition of bleach to the return sludge at this plant has increased the beneficial action of pre-chlorination.

Chlorination of effluents from creameries and canning plants has resulted in the prevention of odors in the receiving streams. The application of chlorine to packinghouse wastes is reported to result in the effective precipitation of putrescible proteins and separation of fats.

Correction

In the abstract of the article, "The Construction and Operation of the Secondary-Digestion Tanks at the Tafelwerder Treatment Plant in Halle," by Heilman and Müller, SEWAGE WORKS JOURNAL, **3,** 325 (1931), the numbers 264,000 and 660,000, on page 326, line 29, should read 26,400 and 66,000, respectively.

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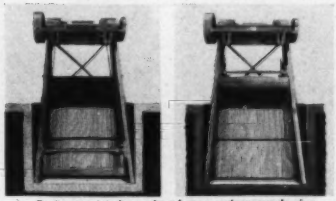

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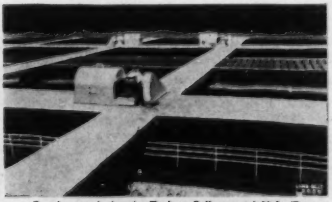

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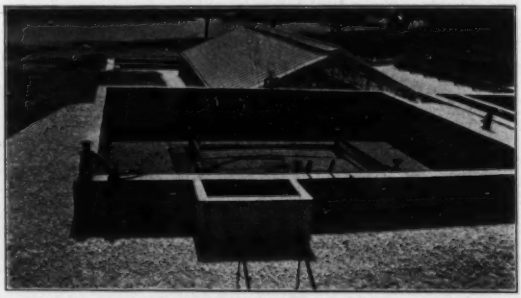

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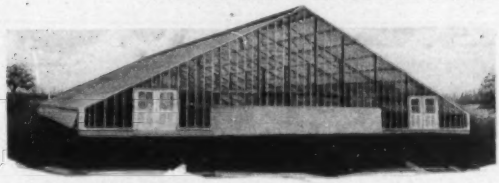

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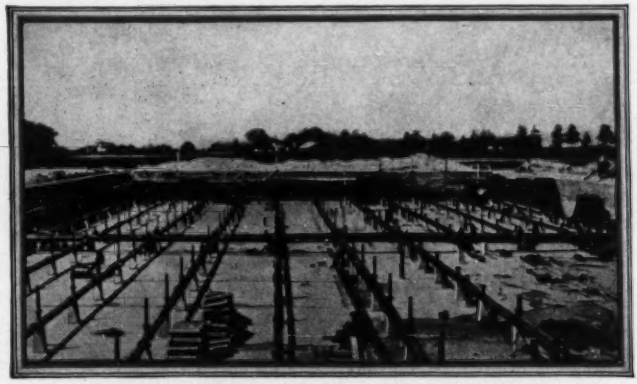

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